U.S. DEPARTMENT OF COMMERCE
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PB-252 701

DEVELOPMENT OF GUIDELINES FOR IDENTIFICATION AND EVALUATION OF LOCALIZED VIOLATIONS OF CARBON MONOXIDE STANDARDS

GCA CORPORATION

PREPARED FOR
ENVIRONMENTAL PROTECTION AGENCY

JANUARY 1976

EPA-901/9-76-002

GCA-TR-75-35-G(2)

140253

PB 252 701

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FINAL SUMMARY REPORT

Contract No. 68-02-1337
Task Order No. 6

Prepared For
U.S. ENVIRONMENTAL PROTECTION AGENCY
Region I Office
Boston, Massachusetts

January 1976

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

GCA/TECHNOLOGY DIVISION
BEDFORD, MASSACHUSETTS 01730

213

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA 901/9-76-002	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Development of Guidelines for Identification and Evaluation of Localized Violations of Carbon Monoxide Standards		5. REPORT DATE January 1976 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Alan H. Castaline, Theodore P. Midurski, Robert M. Patterson, Arnold J. Soolman		8. PERFORMING ORGANIZATION REPORT NO. GCA-TR-75-35-G(2)
9. PERFORMING ORGANIZATION NAME AND ADDRESS GCA Corporation GCA/Technology Division Bedford, Massachusetts 01730		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. 68-02-1337 TO No. 6
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Region I Office Boston, Massachusetts 02203		13. TYPE OF REPORT AND PERIOD COVERED Final Report 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

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17. KEY WORDS AND DOCUMENT ANALYSIS **PRICES SUBJECT TO CHANGE**

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Atmosphere Contamination Control Atmospheric Models Carbon Monoxide Exhaust Gases Traffic Engineering Transportation/Urban Planning	Air Pollution Model Automobile Exhaust Highway Corridor Air Quality Analyses Relationships Between Traffic and Nearby Air Quality	13/13B
18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 213
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE $7.75-2.25

EPA Form 2220-1 (9-73)

EPA-901/9-76-002 GCA-TR-75-35-G(2)

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Task Order No. 6

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This report was furnished to the U.S. Environmental Protection Agency by the GCA Corporation, GCA/Technology Division, Bedford, Massachusetts 01730, in fulfillment of Contract No. 68-02-1337, Task Order No. 6. The opinions, findings, and conclusions expressed are those of the authors and not necessarily those of the U.S. Environmental Protection Agency or of the cooperating agencies. Mention of company or product names is not to be considered as an endorsement by the U.S. Environmental Protection Agency.

ABSTRACT

This report describes the development of a series of guidelines for the identification and evaluation of localized violations of carbon monoxide air quality standards. Guidelines for first-stage analysis (screening) were based upon the EPA Indirect Source Guidelines and generalized traffic data. Guidelines for second-stage analysis specify the use of available air quality models. Guidelines for selecting among alternative control measures describe several alternative measures, quantify their air quality impact with data from the literature and from new analyses, and describe their other impacts. Guidelines were tested on 51 locations in Waltham, Massachusetts, data for which is provided in this report. This volume describes development of all the guidelines and includes revised draft guidelines for modeling and for selection of control measures; guidelines for screening were published in a separate volume.

CONTENTS

		Page
Abstract		iii
List of Figures		v
List of Tables		vi
Acknowledgments		viii
Sections		
I	Introduction and Summary	1
II	Development of Preliminary Screening Process	9
III	Development of Procedures for Verifying Hot Spot Potential	45
IV	Development of Guidelines for Hot Spot Modeling and for Selection of Control Measures	58
V	Data Collection in Waltham	79
VI	Observations and Recommendations for Further Study	102
Appendix		
A	Selection of Models for Detailed Analysis	A-1
B	Evaluation of Selected Traffic Engineering Measures and Their Effect	B-1
C	Location Sketches	C-1

FIGURES

No.		Page
1	Volume Demand - Capacity Ratio in a Freeway or Expressway Lane Versus CO Concentration Impact at a Perpendicular Distance of 10 Meters, 1977	13
2	Volume Demand - Capacity Ratio in a Lane on a Major Street Versus CO Concentration Impact at a Perpendicular Distance of 10 Meters, 1977	
3	Relative Concentration of CO Versus Perpendicular Distance From a Traffic Lane With Freely Flowing Traffic	20
4	Maximum Impact of Traffic in an Approach Lane Upstream From a Signalized Intersection at a Receptor Site Located at a Perpendicular Distance of 10 Meters, 1977	25
5	Maximum Impact of Traffic in a Lane Downstream From an Intersection at a Receptor Site Located a Perpendicular Distance of 10 Meters Away, 1977	26
6	Relative Concentration of CO Versus Perpendicular Distance From a Traffic Lane Near a Signalized Intersection	28
7	Impact of Traffic Upstream From a Nonsignalized Intersection on CO Concentrations at a Receptor Site Located a Perpendicular Distance of 10 Meters Away, 1977	34
8	Relative Concentration of CO Versus Perpendicular Distance From a Traffic Lane Near a Nonsignalized Intersection	36
9	Examples of Effects on Screening Curves of Variations in Parameter Assumptions	42
10	Reproduction of Summary Tabulation, Hot Spot Verification Analysis, Waltham	97

TABLES

No.		Page
1	Assumptions for CO Concentration Computations	39
2	Variation in Estimated Parameter Values for Sensitivity Analysis	40
3	Changes in Parameters Versus Changes in Allowable Volumes	41
4	Emission Indices by Vehicle Type for Three Regions	50
5	Calculation of Emission Rate Correction Factor for 15 mph	62
6	Existing Characteristics of Example Intersections in Waltham, Mass.	64
7	Calculation of Required Reduction in Automotive Emissions for Example Cases	66
8	Relative Traffic Volumes With Proposed Improvement Programs, Waltham	68
9	Effect of Example Alternative Improvements on CO Levels at Two Locations in Waltham	71
10	Data Requirements and Sources for Waltham Screening	82
11	Locations in Waltham Screened for Hot Spot Potential	84
12	Locations in Waltham Analyzed for Verification of Hot Spot Potential	85
13	Traffic Distribution at ATR Locations, Waltham	87
14	Traffic Distribution Classification of Hot Spot Sites	88
15	Projected Growth Rates for Traffic on Various Highway Classes - 1972 to 1980	89

TABLES (continued)

No.		Page
16	Waltham Roadway Classification	89
17	Vehicle-Type Distribution for Various Street Classifications in Waltham	90
18	Vehicle Type Distribution Classification	92
19	Signalized Intersections G/Cy Apportionment	94
20	Locations in Waltham With Hot Spot Potential	96

ACKNOWLEDGMENTS

Numerous individuals and several organizations have been helpful in carrying out the work presented in this report. For these contributions GCA/Technology Division extends its sincere gratitude.

Project direction and technical guidance were given by the Project Officer, Mr. John Calcagni of Region I, and by Mr. Gary Hawthorne and Mr. Jerry Kurtzweg of the Office of Transportation and Land Use Policy, U.S. Environmental Protection Agency.

Several state and local agencies supplied information and other assistance for this work. Particular thanks go to the Bureau of Transportation Planning and Development of the Massachusetts Department of Public Works, the City of Waltham, Massachusetts, and the Office of Air Quality Planning and Standards of the U.S. Environmental Protection Agency.

SECTION I

INTRODUCTION AND SUMMARY

INTRODUCTION

Background

Amendments to the Clean Air Act enacted in 1970 require that National Ambient Air Quality Standards be attained by a certain date and then maintained thereafter, throughout the United States. The attainment date is specified by the Act to be 31 May 1975, or a later date set by the Administrator of EPA for particular geographic areas but in no case later than 31 May 1977.

To attain the National Ambient Air Quality Standards (NAAQS's), each state has developed a plan, referred to as the State Implementation Plan or SIP, that describes the specific actions to be taken. These plans are developed in conjunction with, approved by, and sometimes supplemented by, EPA. Many SIP's have included elements that are directed at control of the pollutants emitted primarily by automobiles. These elements of the SIP are referred to as Transportation Control Plans or TCP's.

The TCP for the Boston area, as revised in June 1975,* requires that a procedure be devised and implemented " . . . to identify urban and suburban core areas and roadway/intersection complexes within the Boston Intrastate Region which violate the national ambient air quality standards for carbon monoxide."[1] The present report stems from that requirement.

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*At the present time (January 1976), this TCP is a plan promulgated by EPA as an addition to the Massachusetts SIP.

The reason for the requirement in the Boston TCP to develop a procedure for locating violations of the CO standard is that CO is a nonreactive pollutant whose concentration is highly variable from one geographic location to another. Thus, the relatively few existing CO monitoring stations are believed to: (1) reflect CO levels only in the immediate vicinity of the monitors; and, (2) not provide any indication of CO levels at other locations.

Carbon monoxide levels at street level are produced almost exclusively by automotive emissions. Local CO levels are thus primarily a function of the automobile traffic in the immediate vicinity. The concept behind the present report is that one can locate "hot spots" — locations with excessive CO concentrations— by examining available traffic data and computing vehicular emissions of CO and resulting concentrations of CO, in lieu of measuring air quality at all possible locations.

This report describes the development of guidelines intended (initially) to satisfy the immediate requirement of the Boston TCP for a procedure to locate CO hot spots. The procedures are general, however, and can be applied throughout the United States.

At the outset, EPA requested that GCA use the existing Indirect Source Guidelines[2] as the basis for the present hot spot guidelines. The reason for this was that the Indirect Source Guidelines were designed to be used with traffic data as the primary input, which was also needed for the hot spot guidelines, and were widely available. (Furthermore, GCA had participated in the development of the Indirect Source Guidelines.) The Indirect Source Guidelines were originally developed to aid in evaluation of CO levels near roadway intersections adjacent to "indirect sources" such as shopping centers and airports.

This, then, is a report of the development of hot spot guidelines from the existing Indirect Source Guidelines. The hot spot screening guidelines themselves are presented in a companion volume;* guidelines for modeling and for selection of control measures are in Appendices A and B of this volume. Much of the text in this volume was previously contained in four technical memoranda issued during the project.

Concept

The initial concept of the process for identifying and resolving CO hot spots was to have a two-step process: screening and modeling. Screening would identify the potential hot spots, while modeling, in conjunction with monitoring of traffic and air quality, would be used for a more exact analysis and for analysis of alternative improvements.

As the project proceeded, however, a two-part screening process evolved. The first part is a new screening guideline, based upon but simpler than the Indirect Source Guidelines. The second part of the screening process is to use the Indirect Source Guidelines directly, to refine the initial screening. The more-detailed second part of the screening step may have three functions:

1. It allows refinement of the screening by using local data in lieu of generalized assumptions, and provides a more quantitative output. Some planners may wish to perform the second part to more thoroughly substantiate the results of the screening.
2. In some instances it may be detailed enough to substitute for modeling as a tool for evaluation of alternative control measures.
3. In this development project, it served to verify the general results of the test screening of Waltham, Massachusetts.

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*The companion volume, referred to throughout this report as the screening guidelines or guideline volume, is reference 3.

SUMMARY

Development of the Preliminary Screening Guidelines

Section II describes the development of the preliminary (first stage) screening guidelines. In essence these screening guidelines graphically portray the results of repeated applications of the Indirect Source Guidelines. The primary input parameter is traffic volumes. For each situation, there is a critical volume above which the potential for a violation of the CO standard exists, according to the model implicit in the Indirect Source Guidelines. Thus, knowing the traffic volumes one can tell at a glance whether a given location is a potential hot spot.

Separate techniques were necessary for three broad categories: signalized intersections, nonsignalized intersections, and midblock locations. Furthermore, there are separate curves for particular types of locations within each category, such as freeways versus nonfreeways in the midblock category, two-lane versus four-lane approaches in the intersection categories, and so on.

Because the effort here was directed toward development of a general guideline for identifying carbon monoxide hot spots, consideration had to be given to several issues that have an influence on the methodology being utilized. First, the guidelines will be used to evaluate literally hundreds of street sections and intersections within any municipality; therefore the parameters considered must be general enough to require the absolute minimum of data input, yet the process must yield a reliable assessment of hot spot potential. Second, the process should be relatively simple and capable of being accomplished quickly, utilizing data which is ordinarily available from state or city agencies. Third, the process is intended to be applicable to any city or town where the existence of a hot spot problem is suspected. These factors, plus the fact that traffic operating characteristics are often highly varied among similar locations (for example, among signalized intersections), indicated that the screening process had to involve a very general approach, relying to a great extent on the validity of applying an assumed set of conservative parameters in order to reduce to a minimum the number of variables which must be considered in the process.

Consequently the screening guidelines were produced by making generalized assumptions about several of the variables in the Indirect Source Guidelines, thus simplifying the amount of data and computing needed for CO assessment. A sensitivity analysis verified the reasonableness of the simplifying assumptions and shows the direction of the effects on air quality of variations in the parameter assumptions.

Development of the Verification Guidelines

Section III describes the development of the second-stage (verification) guidelines. Whereas the initial screening process is intended to be simple and efficient, requiring a minimum amount of data, the verification process is intended to use additional data specific to each location. As opposed to the go/no-go result of the preliminary screening, the verification guidelines provide a calculated CO level.

The verification guidelines are, to a large extent, merely a detailed explanation of how to use the original Indirect Source Guidelines for hot spot screening. Section III therefore discusses only certain specific issues that affect the recommended techniques. Discussion focusses on adjustment of emission factors for local vehicle mix, adjustment for tail pipe controls, adjustment for background CO levels, and certain minor adjustments that were necessary.

As mentioned earlier, the verification screening is sufficiently detailed that in some cases it may be adequate as a tool for evaluation of alternative control measures.

Development of the Guidelines for Modeling and Planning Hot Spot Improvements

Section IV describes GCA's approach to the development of guidelines for: (1) modeling hot spots; and, (2) planning improvements to hot spots. The text provides only a brief outline of the development, because the development was largely straightforward and obvious from the guidelines themselves. GCA's approach relied heavily upon past practice, and included the performance of some special analyses to quantify the impact of some example control measures that have been implemented. The intent was to provide "catalogs" of alternative modeling techniques and of alternative control measures.

To demonstrate the planning process and identify issues associated with representative control measures, extensive use was made in the draft planning guidelines of text drawn from previous analyses of TCP-type measures. In addition, Section IV of this report presents a preliminary example analysis of alternative improvements to downtown Waltham, Massachusetts, using example alternatives previously proposed by others for these locations.

The planning guidelines require further development and have not been included in the guideline volume. The preliminary guidelines for modeling and for selection of control measures appear as Appendices A and B of this volume.

Data Collection in Waltham

Section V discusses the collection of data in Waltham, Massachusetts, performed to provide a basis for testing the screening guidelines on actual locations. Waltham was used because it is the subject of a requirement in the Boston TCP for the development of measures to control CO hot spots in that city.

Data was collected on street characteristics, traffic volumes, traffic signals, and the local vehicle type classifications.

Section V also summarizes the hot spot screening of Waltham. Fifty-one locations were initially screened. Of these, 30 were shown to be potential hot spots after two stages of screening.

Observations and Recommendations

Section VI presents several observations and recommendations for further study, based upon this project. Issues that are discussed include both the technical details of the procedures and the theoretical premise for determining hot spots.

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1. 40 CFR 52.1164, at 40 FR 25170 (June 12, 1975).

2. Guidelines for Air Quality Maintenance Planning and Analysis, Volume 9: Evaluating Indirect Sources. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711. Publication Number EPA-450/4-75-001. January 1975.

3. Midurski, Theodore P. and Alan H. Castaline. Guidelines for Identification and Evaluation of Localized Violations of Carbon Monoxide Standards. Final Guideline Report. GCA/Technology Division, Bedford, Massachusetts. For: U.S. Environmental Protection Agency, Region I, Boston, Massachusetts. Publication No. EPA-901/9-76-001. January 1976.

SECTION II

DEVELOPMENT OF PRELIMINARY SCREENING PROCESS

GENERAL

Background

This Section describes the development of the guidelines for preliminary screening of potential hot spots of carbon monoxide concentrations. The guidelines themselves are presented in a separate volume.

Screening, as presented in the Volume I guidelines, is a two-part process. Development of the first part, preliminary screening, is described here. Development of the second part, verification of hot spot potential, is described in Section III.

Most of the text in this Section was initially included in Technical Memorandum No. 1 (August 1975), issued during the project to document the research results.

Purpose of Screening

The screening process can be defined as a preliminary investigation of an area to identify specific locations where carbon monoxide concentrations may exceed the NAAQS. With respect to highway networks, the highest concentrations of carbon monoxide typically occur in the vicinity of intersections where vehicle speeds are low and much vehicle acceleration, deceleration and idling takes place. Concentrations along limited access highways or at midblock locations on arterial streets may also exceed the NAAQS; therefore these locations must be considered in the screening process as well. Owing to major differences in emission characteristics - and hence in pollutant concentrations - separate screening techniques were developed for highway intersections and midblock locations. Also, emission characteristics of intersections will vary substantially depending on whether or not traffic signals are utilized; therefore separate procedures were also developed for both signalized and unsignalized intersections.

Screening Concept

Inasmuch as the effort here was directed toward development of a general guideline for identifying carbon monoxide hot spots, consideration was given to several issues which will have an influence on the methodology utilized. First, in effect, the guidelines will be used to evaluate literally hundreds of street sections and intersections within any municipality; therefore the parameters considered must be general enough to require the absolute minimum of data input, yet the process must yield a reliable assessment of hot spot potential. Second, the process should be relatively simple and capable of being accomplished quickly, utilizing data which is ordinarily available from state or city agencies. Third, the process should be applicable (with perhaps minor modifications) to any city or town where the existence of a hot spot problem is suspected. These factors, plus the fact that traffic operating characteristics are often highly varied among similar locations (for example, among signalized intersections), indicated that the screening process should involve a very general approach, relying to a great extent on the validity of applying an assumed set of conservative parameters in order to reduce to a minimum the number of variables which must be considered in the process.

In general, then, the screening process involves establishing a relationship between air quality and several general traffic operating characteristics within the vicinity of an intersection or midblock section, based on information provided in the Indirect Source Guidelines.

The need for further analysis of a particular location will then be based on whether a potential air quality problem is indicated by the initial screening procedure.

Two standards exist for maximum carbon monoxide concentrations - the first, 35 parts per million (ppm) applies to a 1-hour average concentration, while the second, 9 ppm, applies to an 8-hour average concentration. For most highway applications, the 8-hour standard is most often violated; therefore, the screening process focuses on the 8-hour average concentration.

PRELIMINARY SCREENING

The implied relationship between air quality and traffic operating characteristics actually is a relationship between air quality and emissions intensity. In the vicinity of highways, emissions intensity depends on parameters such as traffic volume, emission characteristics of the vehicle fleet, quantitative and qualitative operating characteristics (capacity and level of service) of the roadway or intersection, and the actual orientation from the emissions source (e.g., the distance from and height above the traffic lane). Also contributing to the emissions intensity at any location is the background concentration which results from extra- and intraurban diffusion of the pollutant (carbon monoxide), and the prevailing meteorological conditions (macroscale and microscale).

Of the parameters outlined above, capacity and volume characteristics will vary most significantly among locations, while it can be assumed that the other parameters are constant throughout an area. Therefore, the preliminary screening process is based on an air quality-emissions intensity relationship where emissions intensity is the independent variable and, also, where emissions intensity is considered to be a function of two variables - volume demand and facility capacity - and a constant set of factors to account for the vehicle-fleet emissions characteristics, orientation and distance from the source, background concentrations, and prevailing meteorology.

Each type of roadway location will be separately discussed in the following text.

UNINTERRUPTED FLOW CONDITIONS

General

For conditions of uninterrupted flow on streets and highways, vehicle speed is a key determinant of emissions intensity. Because average travel speeds vary to such a great extent throughout a highway network, it is necessary to separately consider facilities where speed characteristics are expected to be quite dissimilar. For this analysis, two facility-types were considered, these being (1) freeways, expressways, or other limited access, high speed highway classes; and (2) arterial streets and highways.

The Indirect Source Guidelines[1] present a family of curves expressing an empirical relationship between air quality and various combinations of roadway volume and capacity (see Figures 1 and 2).* Again, other parameters, mainly meteorology, emission factors, and certain operating characteristics, have been included, but as nonvariables (the reader is referred to Sections 6.0 to 6.6 of the Indirect Source Guidelines for a discussion of the assumptions made regarding these parameters). An implication of the air quality-volume-capacity relationships expressed by these curves is that for every given value of lane capacity there is a critical volume demand which, once reached, will generate concentrations

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*Curves presented here have been adjusted to reflect 1977 conditions, as described later.

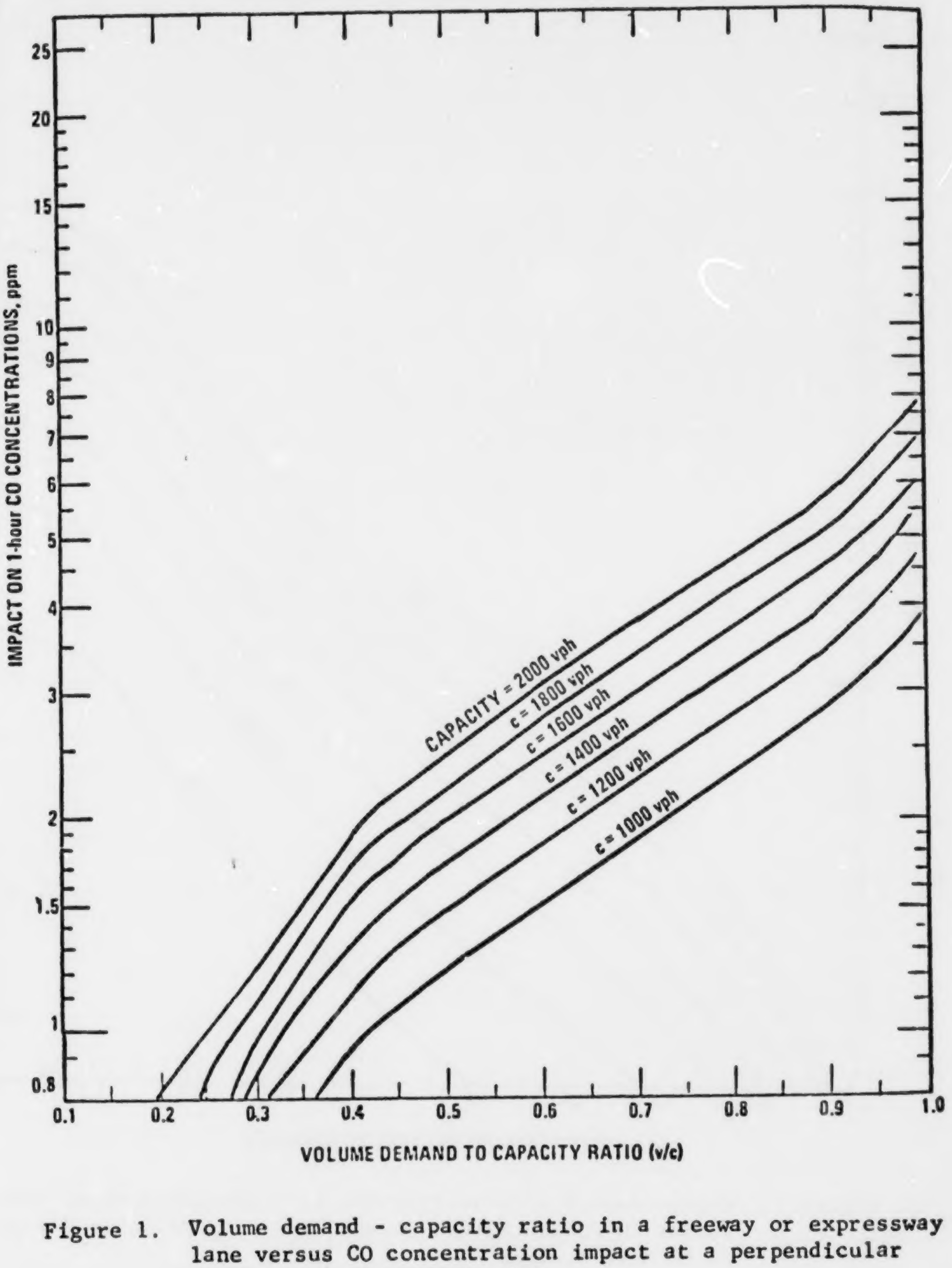

Figure 1. Volume demand - capacity ratio in a freeway or expressway lane versus CO concentration impact at a perpendicular distance of 10 meters, 1977

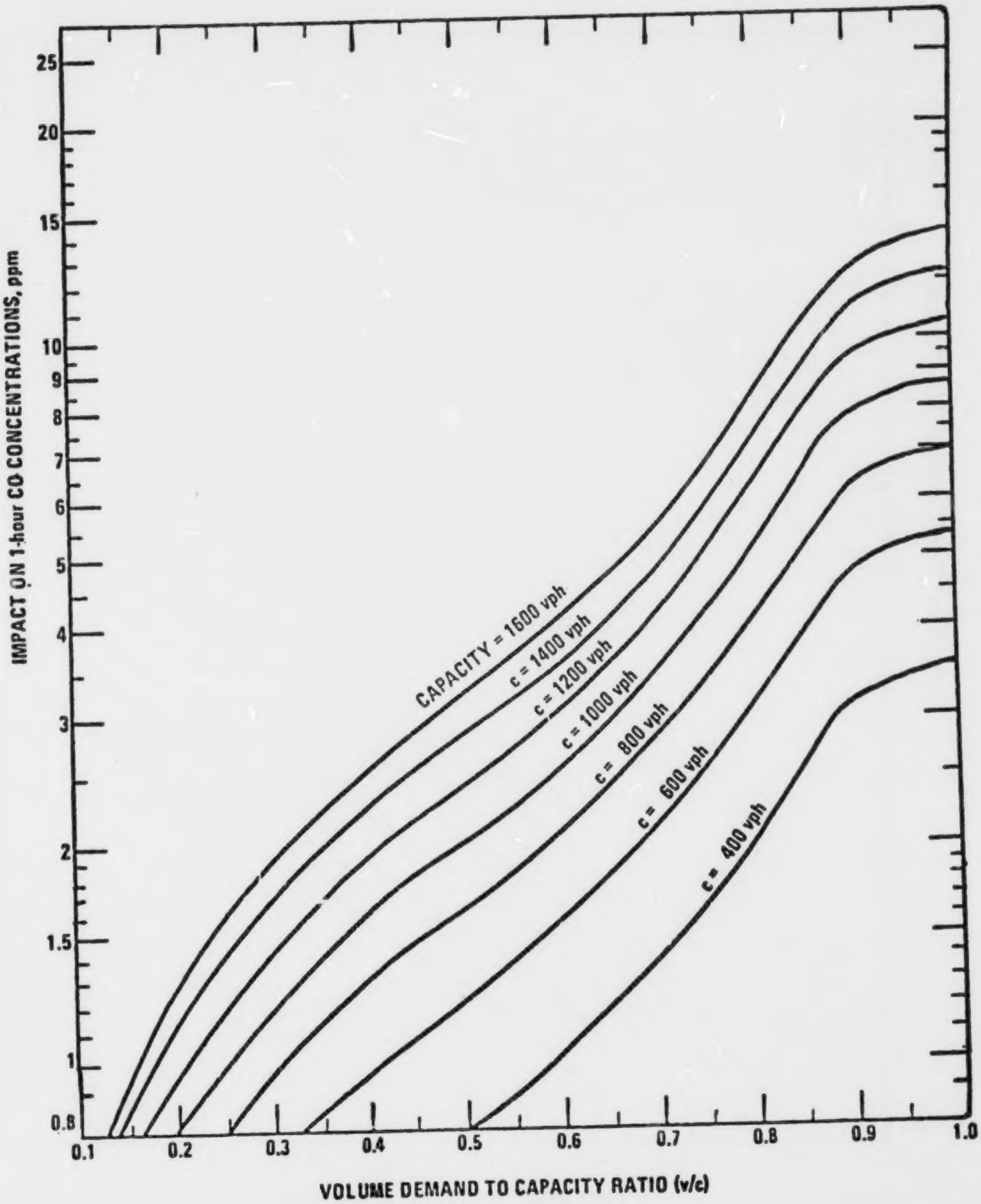

Figure 2. Volume demand - capacity ratio in a lane on a major street versus CO concentration impact at a perpendicular distance of 10 meters, 1977

of carbon monoxide which are in violation of the National Ambient Air Quality Standards. Determination of these critical volumes provided the basis for the preliminary screening process.

As mentioned previously, ambient concentrations of carbon monoxide at any location on an urban highway network are actually a result of emissions from the nearby source (highway) plus a background concentration resulting from emissions generated at more distant sources. Consequently, it was necessary to develop provisions to account for background concentrations in the screening guidelines. Various methods are suggested in the Indirect Source Guidelines for determining the background concentration for a particular area; however, these methods require a certain amount of short-term, local air quality monitoring and also assume that historical ambient air quality data are available from a permanent monitoring station within the general area of the site. Given the cost and time requirements for short-term monitoring, and the extent of current long-term air quality monitoring programs, it is highly unlikely that these procedures could be used in the context of hot spot verification. In an attempt to develop a simple yet reasonable method for identifying background concentrations, the results of diffusion modeling (using the APRAC diffusion model) efforts in three New England cities were analyzed. The data available for analysis included estimates of background concentrations at 20 receptors in each city computed from local traffic data, and local meteorological data for a 1-year period. The averages of the maximum background concentrations computed for the 20 receptors in each city were 2.5 ppm, 2.9 ppm amd 5.1 ppm (averaged over 8 hours). These data were developed for conditions during 1973-74. If these averages are projected for 1977-78 conditions, the results (conservatively) are 1.8 ppm, 2.0 ppm, and 3.6 ppm. Clearly, this shows that there may be significant variations among cities with regard to background concentrations. However, it can be postulated that a value of about 3.6 ppm may be representative of the upper portion of the range in which background levels occur (8-hour average background concentrations, that is). Assuming that this is a reasonable conclusion, then the corresponding 1-hour average background can be estimated by applying the correlation factor (0.7) developed for relating 8-hour to 1-hour average concentrations. This results in an estimated 1-hour average background concentration of about 5.1 ppm or, say, 5 ppm.

It is again stressed that the need for this "standard value" is that it is anticipated that local data may not be available in all instances to determine actual background concentrations. Therefore, the standard value provides for use where the actual value cannot be readily determined using existing data.

Data and procedures in the Indirect Source Guidelines are oriented to the maximum 1-hour average concentration of carbon monoxide while it was stated that the 8-hour average concentration is of interest here. The Guidelines suggest that there is a relatively high, positive correlation between the daily maximum 1-hour concentration and the maximum 8-hour average concentration, however. Analysis of air quality data from a number of continuous monitoring stations[3,4] indicated that the relationship between the maximum 1-hour and 8-hour average concentrations can be expressed, simply, by:

$$X_8 = PX_1 \qquad (1)$$

where X_8 = highest expected 8-hour average concentration

X_1 = highest 1-hour average concentration (in same 8-hour period)

P = 8-hour correlation factor.*

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*The Indirect Source Guidelines discuss a "persistence factor" (pp. 20, 31, 32), which is similar to the 8-hour correlation factor, P, above. The equation here is a simple empirical relationship between observed 1-hour and 8-hour CO levels. Variations in meteorology and in traffic flows thus are implicit in the calculated factor. In contrast, the Indirect Source Guidelines factor explicitly calculates the adjustments for variations in traffic and meteorological conditions. The difference in the factors resulted from slightly different needs — the Indirect Source Guidelines are primarily for forecasting CO levels from sources that do not yet exist.

While the value of the correlation factor can be expected to vary depending on local traffic and meteorological characteristics, data analysis indicates that a value of 0.7 may be considered appropriate, especially in the range of 1-hour average concentrations of from 10 ppm to 20 ppm. In this analysis, monthly summaries of carbon monoxide concentrations measured at several monitoring stations in three cities were reviewed. The analyses consisted of determining the ratios of the maximum 8-hour average concentrations to the maximum daily 1-hour average concentrations for various monitoring sites in each city. The maximum 8-hour average concentration used in the analyses included the maximum daily 1-hour average concentration in its averaging period. Further, these ratios were examined for three ranges of maximum daily 1-hour average concentrations — where the maximum 1-hour average was (1) between 0 and 6 ppm, (2) between 6 ppm and 10 ppm, and (3) 10 ppm or greater. Considering the higher range separately, the analysis indicated that for moderately active downtown locations (locations typified by occasional traffic congestion) with apparently good atmospheric ventilation (that is, fairly wide streets and sidewalks and building heights generally not exceeding five or six stories), the ratio of the maximum 8-hour average concentration to the maximum 1-hour average concentration ranges from about 0.6 to 0.7. For downtown areas where heavy traffic congestion occurs throughout much of the day and where ventilation is somewhat restricted by narrow streets and tall buildings, values of from 0.7 to 0.8 were indicated for this ratio. It is highly likely that conditions in most areas where hot spot analyses are conducted will be somewhat less severe (with regard to traffic conditions and ventilation) than those in the congested area referred to here. Given this assumption, it was decided that the value of 0.7 could be considered "reasonable" for use as a "standard value" to describe the ratio of the maximum 8-hour average concentration to the maximum 1-hour average concentration, for cities and towns lacking sufficient data to permit development of a more specific value. Again, the verification procedure allows the use of a locally-derived 8-hour correlation factor.

The maximum 8-hour average concentration of carbon monoxide for a particular location, then, can be expressed by the general equation:

$$X_8 = (X_1 + X_B) P \tag{2}$$

where X_8 = the estimated maximum 8-hour concentration
X_1 = the total estimated concentration contributed by a nearby source (roadway)
X_B = the 1-hour average background concentration, assumed to be 5 ppm
P = 8-hour correlation factor = 0.7

If X_8 is set equal to the National Ambient Air Quality Standard for 8-hour concentrations (9.0 ppm) then the only unknown in the equation becomes X_1, or:

$$X_1 = \frac{X_8 - X_B P}{P} = \frac{9.0 - (5.0)\ (0.7)}{0.7} = 7.85 \text{ ppm}$$

Therefore, for every roadway condition where the calculated 1-hour average concentration contributed by the roadway is about 7.85 or, say, 8 ppm, there is a potential for violations to the 8-hour standard.

The relationships developed in Figures 1 and 2 are representative of concentrations resulting from traffic in a particular lane, measured at a receptor located 10 meters from the edge of that lane. Therefore, in analyzing a street section, the calculated concentration is actually a summation of individual lane-by-lane concentrations. Also, since the distance from the edge of each lane to the receptor will differ, an adjustment must be made to each lane concentration. The expected 1-hour concentration attributable to roadway traffic, measured at a distance "d" from the edge of that roadway, can be expressed by the equation:

$$\chi_{1d} = \sum_{i=1}^{n} f_i \chi_i \quad (3)$$

where χ_{1d} = total expected 1-hour concentration measured at a distance, d, from this roadway

χ_i = concentration from lane i measured at a distance of 10 meters from lane i

n = total number of lanes

f_i = distance correction factor based on the distance (in meters) from the edge of lane i to the receptor

Figure 3 provides a curve showing the correction factors (f_i) for lane-edge to receptor distances of from zero to 200 meters.

Using the relationships developed above, the expected 1-hour and 8-hour average concentrations can be calculated for any roadway where the lane volume and lane capacity are known; or, conversely, the traffic volume that will result in a particular concentration of carbon monoxide can be determined, if a specific lane capacity is assumed. This type of analysis was performed for several configurations of limited and uncontrolled access facilities. In the analyses, however, assumptions were required regarding several aspects of traffic flow characteristics and receptor location, as will be discussed below.

Assumptions

The first assumption made was that, in order for the analysis to be relevant, the basic parameter of traffic volume would have to be expressed in terms of average daily traffic (ADT). From this, several qualifying assumptions were then made regarding the typical distribution of traffic. In general, it was assumed that:

- peak hour traffic represents 8.5 percent of the ADT
- the directional split on two-way facilities during the peak hour is represented by a ratio of 2:3

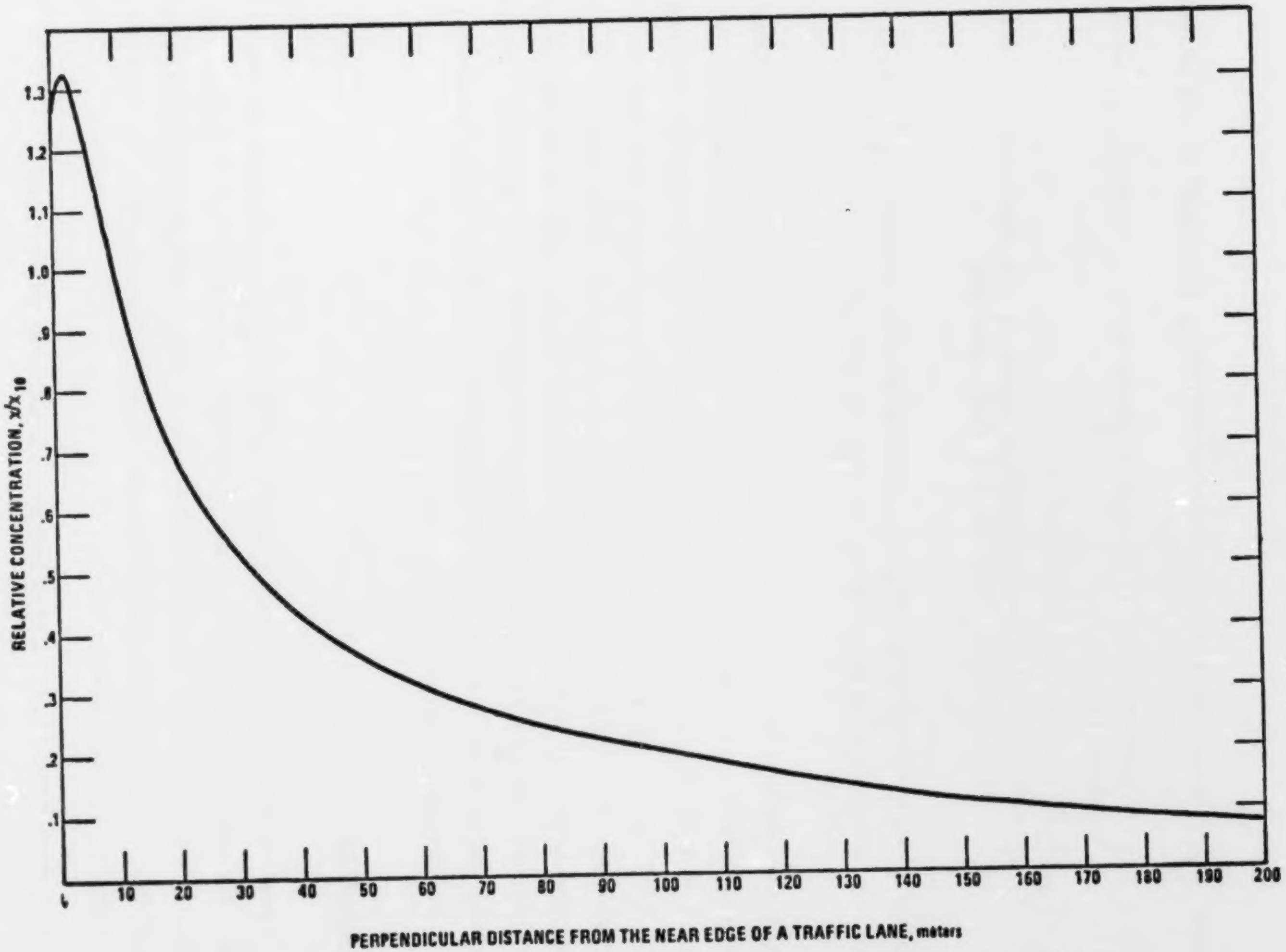

Figure 3. Relative concentration of CO versus perpendicular distance from a traffic lane with freely flowing traffic[1]

- for multi-lane facilities, the volume on the outside lanes (towards the shoulder) is generally lower than the inner lane volumes.

Regarding distance from the roadway to the receptor, it was assumed that, for limited access facilities, the closest reasonable location will be 10 meters from the edge of the outermost travel lane; for uncontrolled access facilities, a minimum receptor distance of 5 meters was assumed. In conjunction with these distances, lanes and medians were assumed to be 3.5 meters and 3.0 meters wide, respectively.

It was also assumed that the assumptions made in the Indirect Source Guidelines would hold true for this analysis. These included assumptions regarding meteorology, emissions, and certain traffic operating characteristics (the reader is, again, referred to Section 6 of the Indirect Source Guidelines for the details of these assumptions). One additional point, however: the emissions concentration-traffic volume-highway capacity relationships presented in the Indirect Source Guidelines assumed that 20 percent of the vehicles using any highway facility would be operating under "cold-start"[*] conditions, and that the ambient air temperature is in the vicinity of 24°C. However, since a highway system is being considered here (rather than, say, a shopping center or other similar source for which the Indirect Source Guidelines were developed) and, typically, the winter months are the most critical with regard to high carbon monoxide concentrations, it was decided that these assumptions were not acceptable. Instead, it was assumed that only about 5 percent of the vehicle population would be operating under cold-start conditions and that for the winter months an assumed ambient temperature of around 0°C would be appropriate. Estimating the percentage of vehicles passing a point on a highway that is operating under cold-start (cold operation) conditions is, at best, an inexact process. Although cold operation is defined as the first 8.4 minutes of operation,[5] studies[6] have shown that approximately 90 percent of the total emissions associated with the cold-start phenomenon occur within the first 2 minutes of vehicle operation. It appears to be a prudent assumption that at any point on most expressways, arterials, and important local streets, most vehicles passing that point have been operating (idling or moving under power) for at least 2 minutes. Therefore 5 percent was selected as being a reasonable figure for vehicles actually operating under cold-start conditions. Correction factors, then, were determined using Supplement 5 of AP-42[5] and the Indirect Source Guidelines[1] to account for these new assumptions. The correction factors determined for the changes in percent cold-operating vehicles, and lower ambient air temperature were 0.62 and 1.54, respectively. The product of these two factors, however is 0.97, or, say 1.0; in other words, these two assumptions do not result in any net effect on computing emissions concentrations using the relationships developed in Figures 1 and 2 from the Indirect Source Guidelines.

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[*] Cold-Start Operation is defined as the first 505 seconds (8.4 minutes) of vehicle operation following a 4-hour and 1-hour engine-off period for non-catalyst- and catalyst-equipped vehicles, respectively.[6]

An additional adjustment was to alter the Indirect Source Guideline charts to apply to 1977 instead of 1975. This was done because the initial application of the screening guidelines is to be in the Boston metropolitan area, whose attainment date is in 1977. According to data in the Indirect Source Guidelines, average CO emissions in 1977 will be 80 percent of those in 1975, for the same conditions, because of the effect of Federal new-vehicle emission controls. Thus, the axes of figures such as Figures 1 and 2 were shifted to produce the required adjustment.

Analysis Results

The result of the analyses performed was the identification of the critical (minimum) ADT which could result in a violation to the National Ambient Air Quality Standard for 8-hour average carbon monoxide concentrations. Figures in the screening guidelines show these critical volumes for various configurations of limited and uncontrolled access facilities. The figures provide the basis for screening roadways where conditions of uninterrupted flow prevail. The resulting procedure provides a "go/no-go" type of analysis. The procedure simply indicates that there is, or is not, a hot spot potential. In the second part of the screening process, to be described later, more quantitative results are obtained.

The procedure for screening highway sections where uninterrupted flow conditions prevail requires only very basic data regarding the roadway network. Essentially, the data required involves traffic volumes and traffic flow characteristics, and general physical data including lane widths, number of travel lanes, and estimates of other capacity determinants such as lateral lane clearance. The data required allows estimates to be made of the facility's lane capacity which, through the use of the curves presented in Volume I, can be related to a corresponding "critical" ADT which, potentially, would result in a violation to the National Ambient Air Quality Standard (NAAQS) for 8-hour average concentrations of carbon monoxide. This critical ADT is then compared with the estimated ADT on the facility during the winter months. A potential hot-spot is indicated when the estimated ADT for the facility equals or exceeds the critical ADT. Critical values should be determined for each roadway section where a change in lane capacity occurs.

INTERRUPTED FLOW CONDITIONS - SIGNALIZED INTERSECTIONS

General

Near signalized intersections, emissions intensity is affected by vehicle operating characteristics including acceleration and deceleration rates, time in idle mode, and total volume. These operating characteristics, in turn, are influenced by such elements as intersection capacity, amount of green (signal) time allocated to each approach, location of the intersection (e.g., rural, residential, or downtown), the proximity of other signalized intersections, and others. Emissions intensity is also related to the physical layout of the intersection with respect to lane configuration as well as receptor location relative to the emissions source. Since there is a large number of variables that can significantly affect carbon monoxide concentrations at signalized intersections, several generalized situations regarding operating characteristics and physical layout of intersections were developed as the basis for the screening process.

The Indirect Source Guidelines present curves expressing relationships between air quality and various combinations of roadway volume and the principal determinant of approach capacity - the ratio of the green time allocated to an approach, to the total signal cycle length. These curves, shown in Figure 4, indicate carbon monoxide concentrations expected from traffic approaching a traffic signal. Emissions from vehicles departing from (downstream of) a signalized intersection are related mainly to the acceleration characteristics of the traffic stream. These acceleration characteristics are a function of the cruise speed attained downstream. Carbon monoxide concentrations as a function of traffic volume and cruise speed are shown in Figure 5. The screening process for signalized intersections was based on establishing air quality-volume-capacity relationships for particular intersection configurations, and relating these to the appropriate air quality standard for carbon monoxide.

As was discussed previously, carbon monoxide concentrations at any point are a result of two components - background emissions and local source emissions. The discussion of background emissions provided in the previous section is also applicable here. For local emissions in the vicinity of signalized intersections, the primary source is considered to be approaching and departing traffic.

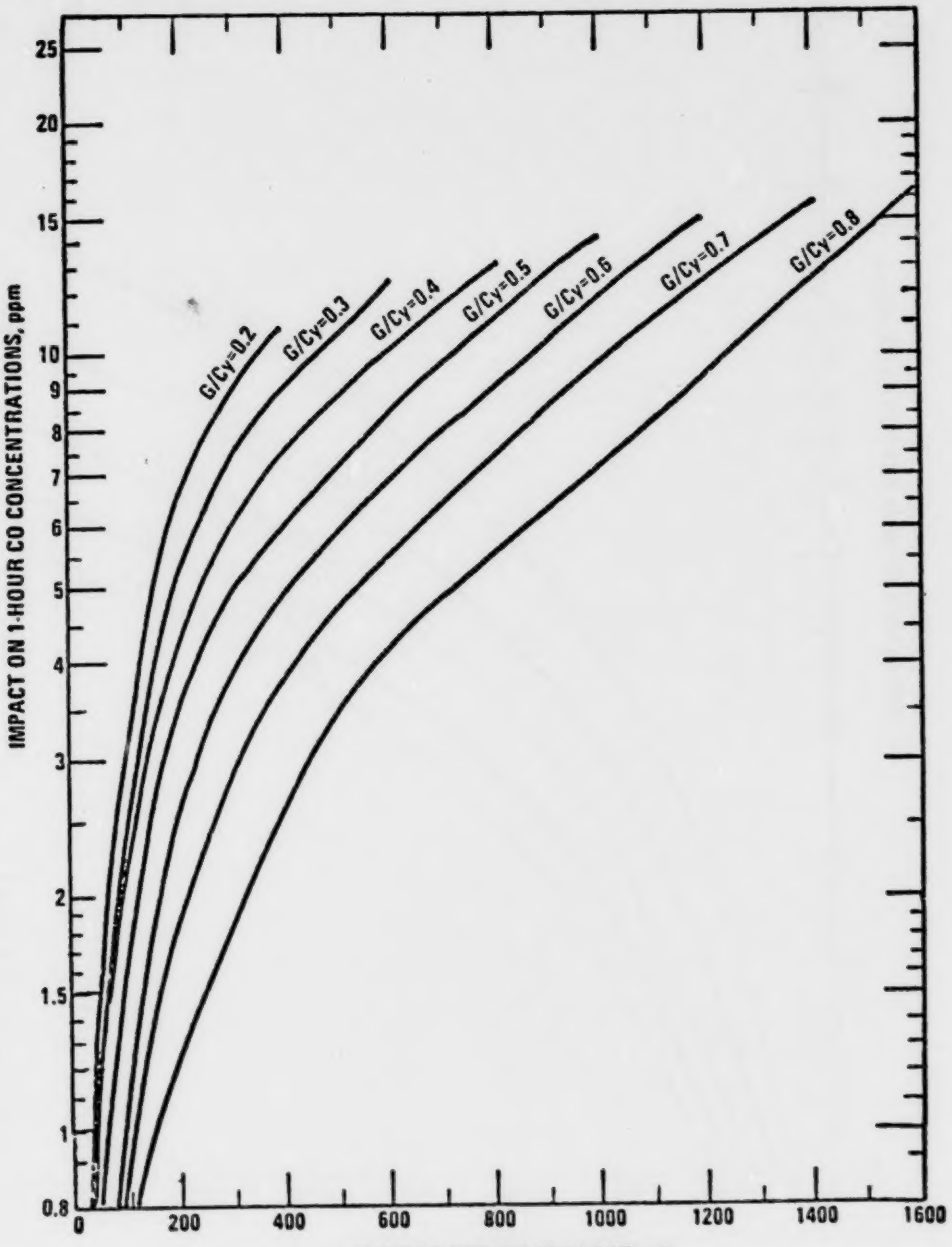


Figure 4. Maximum impact of traffic in an approach lane upstream from a signalized intersection at a receptor site located at a perpendicular distance of 10 meters, 1977

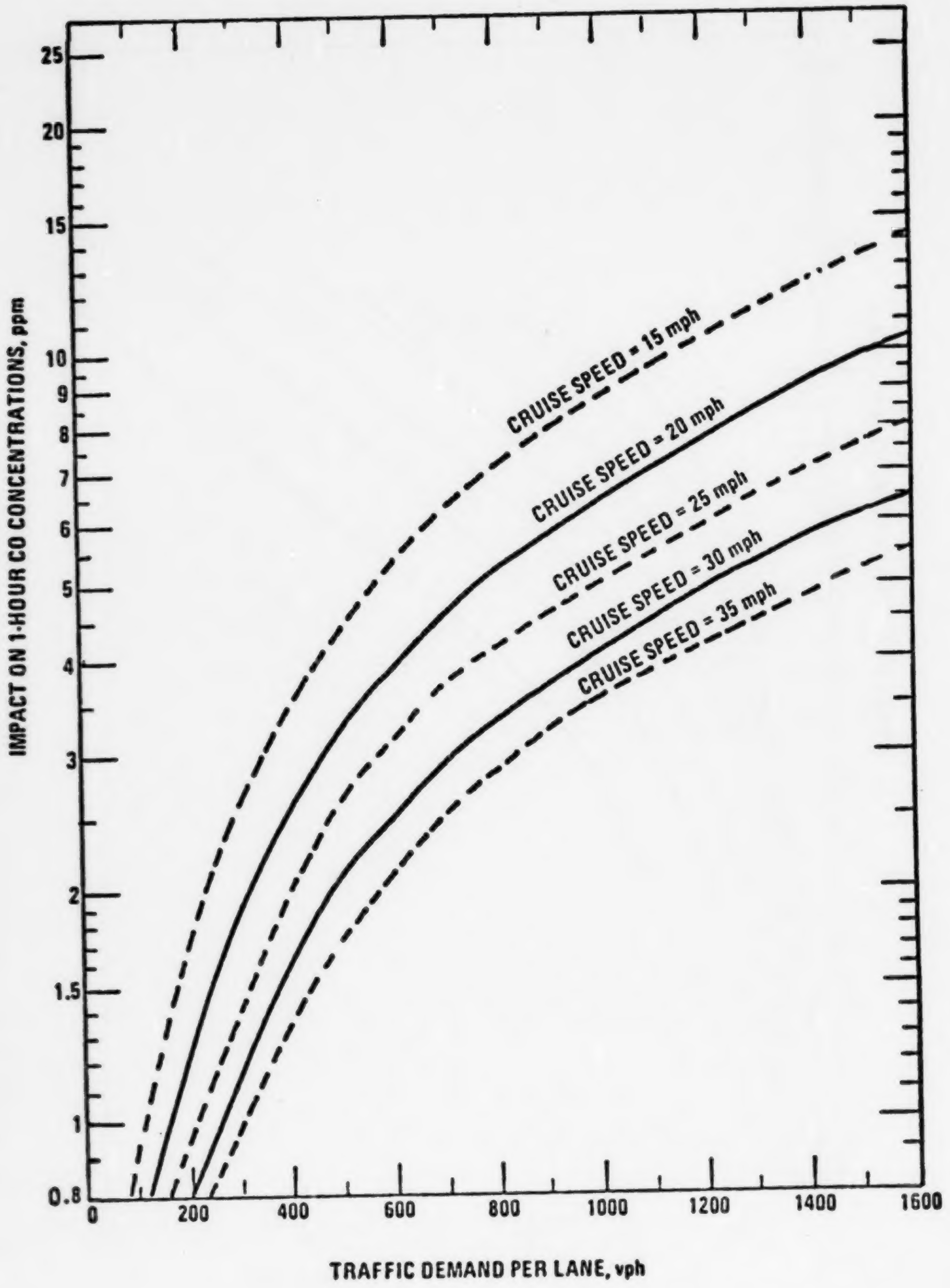


Figure 5. Maximum impact of traffic in a lane downstream from an intersection at a receptor site located a perpendicular distance of 10 meters away, 1977

Insofar as developing a guideline for screening signalized intersections is concerned, the basic concepts that apply are the same as those outlined for screening midblock locations. In other words, certain basic relationships developed in the Indirect Source Guidelines (i.e., those represented in Figures 4 and 5), were utilized as the basis for determining "critical" conditions for a number of general roadway (intersection) configurations. Critical conditions are defined as those that result in calculated 1-hour concentrations of carbon monoxide which, when multiplied by a correlation factor, are equal to the NAAQS for 8-hour average concentrations.

The analysis was performed for a number of common intersection configurations. For the analyses, an 8-hour correlation factor of 0.7 was used; a discussion of the basis for this value was presented in the previous portion of this section regarding uninterrupted flow conditions. Also, the relationships between air quality and operating characteristics shown in Figures 4 and 5 are representative of concentrations expected at a receptor located 10 meters from the edge of a particular lane. Therefore, correction factors were required to compensate for the differences in lane edge to receptor distances that occur when considering a roadway as a whole rather than individual lanes. These correction factors are shown in Figure 6.

A number of assumptions were required in developing a general procedure for assessing the hot spot potential of signalized intersections. These concern mainly traffic volume distribution, receptor distances, and general intersection operating characteristics, as discussed below.

Assumptions

It was assumed, again, that the basic parameter of traffic volume would be expressed as ADT. Also, the following assumptions were used regarding ADT:

- peak hour traffic represents 8.5 percent of the ADT

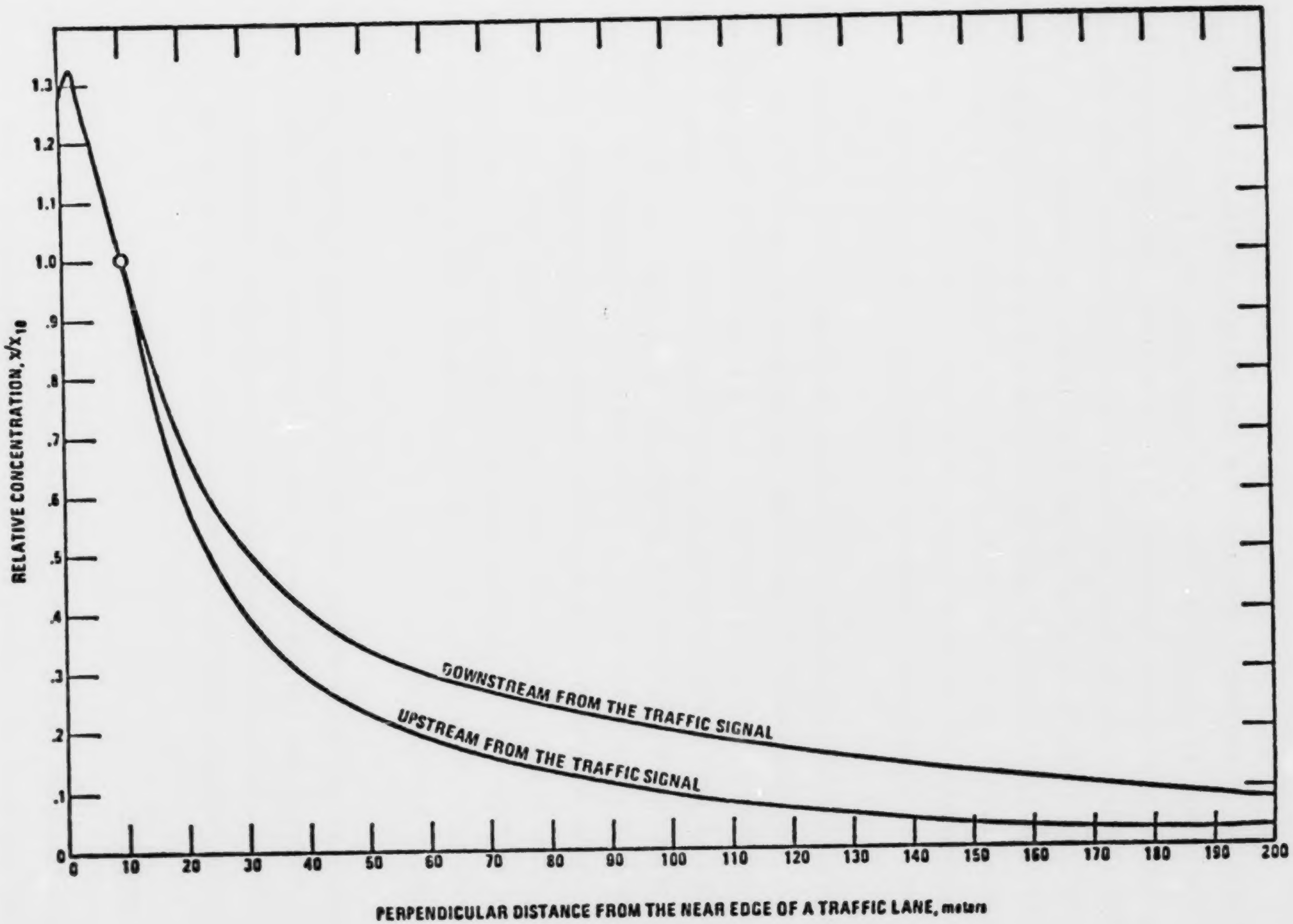
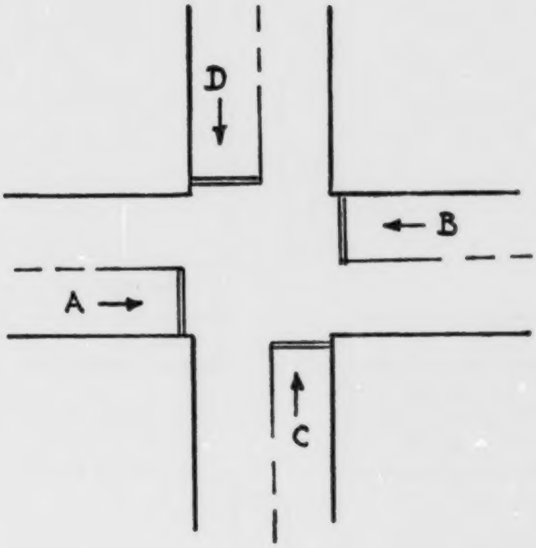


Figure 6. Relative concentration of CO versus perpendicular distance from a traffic lane near a signalized intersection[1]

- an even directional distribution occurs on two-way facilities during the peak hour
- for multilane facilities, the volume on the outside lanes (towards the shoulder) is generally lower than the inner lane volumes.

The distance from the edge of the roadway to the receptor was assumed to be 2 meters. Referring to Figure 6, this results in maximum concentrations at the receptor resulting from traffic in the lane closest to the receptor. Also, lane widths of 3.5 meters were assumed.

Another important assumption utilized is with respect to the determination of the ratio of green time allocated to each approach, to the total signal cycle length (G/Cy).* It was assumed that the G/Cy for any approach is directly proportional to the product of (1) the ratio of the critical lane volume of that approach to the sum of that critical lane volume and the critical lane volume on the opposing roadway and (2) the ratio of total green time to the total signal cycle length. As an example, consider the following sketches.



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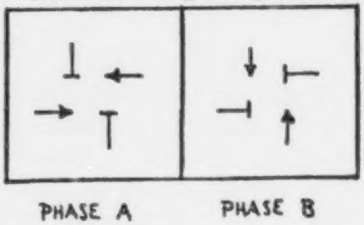
*Defined in the screening guidelines and in The Highway Capacity Manual.[7]

Peak-hour volumes for each approach:

$V_A = 500$
$V_B = 400$
$V_C = 200$
$V_D = 300$

Assumed signal phasing:



Therefore, G/Cy for approach A would be:

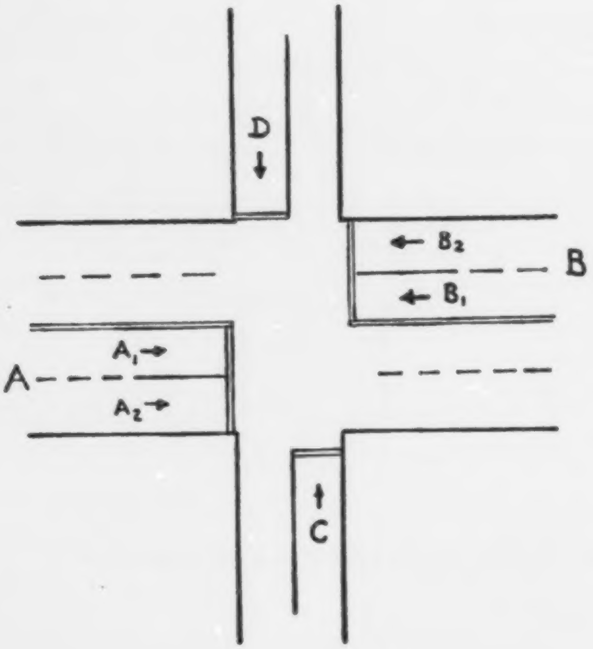
$$G/Cy_A = \left[\frac{500(0.9)}{500 + 300}\right] = \frac{450}{800} = 0.56$$

For approach B, G/Cy would also be 0.56

For approaches C and D,

$$G/Cy_C = G/Cy_D = \left[\frac{300(0.9)}{500 + 300}\right] = \frac{270}{800} = 0.34$$

However, if the same approach volumes occur on the following intersection, the resulting G/Cy's are quite different as shown below.



Peak-hour volumes for each approach:

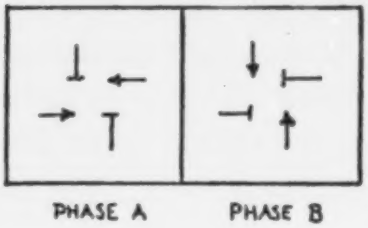
$$V_A = V_{A1} + V_{A2} = 300 + 200 = 500$$

$$V_B = V_{B1} + V_{B2} = 250 + 150 = 400$$

$$V_C = 200$$

$$V_D = 300$$

Assumed signal phasing:



For approaches A and B:

$$G/Cy_A = G/Cy_B = \left[\frac{300(0.9)}{300 + 300}\right] = \frac{270}{600} = 0.45$$

For approaches C and D:

$$G/Cy_C = G/Cy_D = \left[\frac{300(0.9)}{300 + 300}\right] = \frac{270}{600} = 0.45$$

As can be seen from Figure 4, G/Cy and lane volumes are the key parameters in the determination of carbon monoxide concentrations generated at approaches to signalized intersections. However, Figure 5 is somewhat different from Figure 4 in that it is used to estimate concentrations resulting from vehicles departing downstream of this intersection; therefore different parameters are utilized. The parameters used for determining concentrations from vehicles downstream of the intersection are lane volume and cruise speed. Cruise speeds of from 15 to 35 miles per hour are presented in 5 mile-per-hour increments. Two different cruise speed curves were used in developing the screening procedure - the first was the 15 mile-per-hour curve used for conditions where congestion is highly likely (e.g., within urban business districts), while the 30 mile-per-hour curve was used for noncongested areas.

Assumptions regarding cold operation and temperature correction for signalized intersections were the same as those described in the previous section dealing with uninterrupted flow conditions. These assumptions were that the ambient temperature representative of winter operation is $0^{o}C$ and that 5 percent of the vehicles passing any point in the highway network would be operating under cold conditions (the first 2 minutes of operation). These issues are discussed in detail in a previous portion of this section. Data were also adjusted to 1977, as before.

Analysis Results

The results of the analyses was the identification of the critical (minimum) ADT's for several basic configurations of intersecting streets that could result in violations to the National Ambient Air Standard for 8-hour average carbon monoxide concentrations. In the analysis, eight general intersection approach configurations were considered, including:

(a) 4-Lane, 2-Way in congested areas
(b) 4-Lane, 2-Way in noncongested areas
(c) 3-Lane, 2-Way in congested areas
(d) 3-Lane, 2-Way in noncongested areas
(e) 2-Lane, 2-Way in congested areas
(f) 2-Lane, 2-Way in noncongested areas
(g) 2-Lane, 1-Way
(h) 3-Lane, 1-Way

For each of these, five configurations of intersection street-types were analyzed and corresponding "critical" ADT's determined. Thus, a total of 40 separate intersection configurations were evaluated; results are presented in the screening guidelines.

For screening signalized intersections, traffic volume data, physical layout and traffic operational characteristics are of primary importance. The traffic volume and physical/operational characteristics of each leg of the intersection are then related to the physical/operational characteristics of the opposing roadways and, from these, the "critical" volumes are determined for the opposing traffic. If the actual volumes on these cross streets are greater than or equal to the "critical" volumes, a hot spot potential is indicated for the leg being analyzed.

INTERRUPTED FLOW CONDITIONS - NONSIGNALIZED INTERSECTIONS

General

Although nonsignalized, at-grade intersections are by far the most common type of intersection, they are also the least studied with regard to operational characteristics and capacity. Nonsignalized intersections are very seldom a critical factor of capacity or level of service on through routes although they are of great significance with regard to the minor cross route.[7] Typically, when a point is reached where traffic flow on the major route is affected to any degree by traffic from a minor cross street, a signal is installed. To date, most of the research that has been conducted on capacity and operational aspects of nonsignalized intersections has tended to produce data representative of local conditions only.

In perspective, however, nonsignalized intersections are probably the least likely hot spot locations since they are generally characterized by relatively low volumes on the minor cross streets, and produce little, if any, interference to main stream flow. This being the case, the main stream legs of many nonsignalized intersections can be assessed for hot spot potential using the technique described earlier in this section for uninterrupted flow conditions. For the minor street legs, however, a different analysis must be performed.

A relationship has been developed in the Indirect Source Guidelines between certain operational aspects of nonsignalized intersections and carbon monoxide concentrations (see Figure 7). It is noted that this relationship is in terms of volume and the capacity of the cross street approach lanes. If the cross street is a 2-way facility, concentrations from departing traffic must be accounted for as well. This is accomplished through the use of Figure 5.

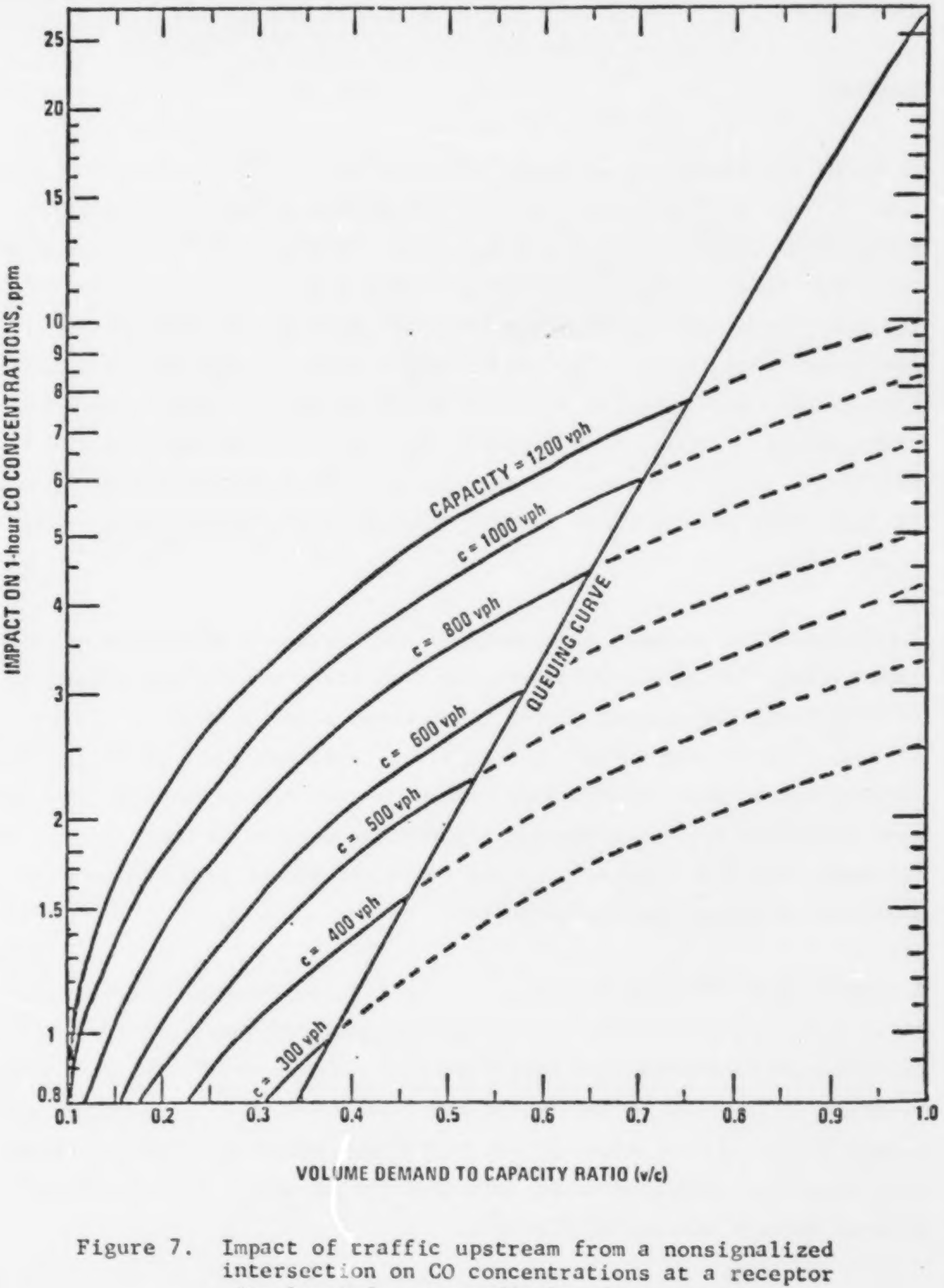


Figure 7. Impact of traffic upstream from a nonsignalized intersection on CO concentrations at a receptor site located a perpendicular distance of 10 meters away, 1977

The concept, then, for developing a screening procedure for nonsignalized intersections was the same as that used in developing the screening process for both uninterrupted flow conditions and signalized intersections. In essence, this involved identifying volume and capacity relationships which result in concentrations (based on the Indirect Source Guidelines) high enough to potentially violate the NAAQS for 8-hour average concentrations of carbon monoxide. Figures 5 and 7 were used to determine the critical volume to capacity relationships for 10 configurations of nonsignalized intersections.

Assumptions

Assumptions used regarding peak hour volume, directional split, and lane distribution were the same as were used for development of the screening procedure for midblock locations. Other parameters concerning emissions factors, meteorology, and certain traffic operating characteristics were also assumed to be identical to those used for midblock locations. The minimum distance from the edge of the nearest lane to a receptor was assumed to be 2 meters. Correction factors to compensate for different lane-edge to receptor distances were obtained from Figure 8.

As was indicated earlier in this section, the procedure for determining the approach capacity of the minor leg at a nonsignalized intersection has not received wide attention in the field of traffic engineering. A procedure was, however, suggested that does provide a reasonable estimate of minor street approach capacity at STOP-sign controlled intersections. This procedure implies that the cross-street approach capacity is a function of the volume and capacity characteristics of the major street flow. More specifically, it is suggested that a value representing the minor street approach capacity can be computed as being the product of (1) the difference between the average lane capacity and the average lane volume for the critical direction of the major street, and (2) a factor that accounts for the lower capacity of an approach where vehicles depart

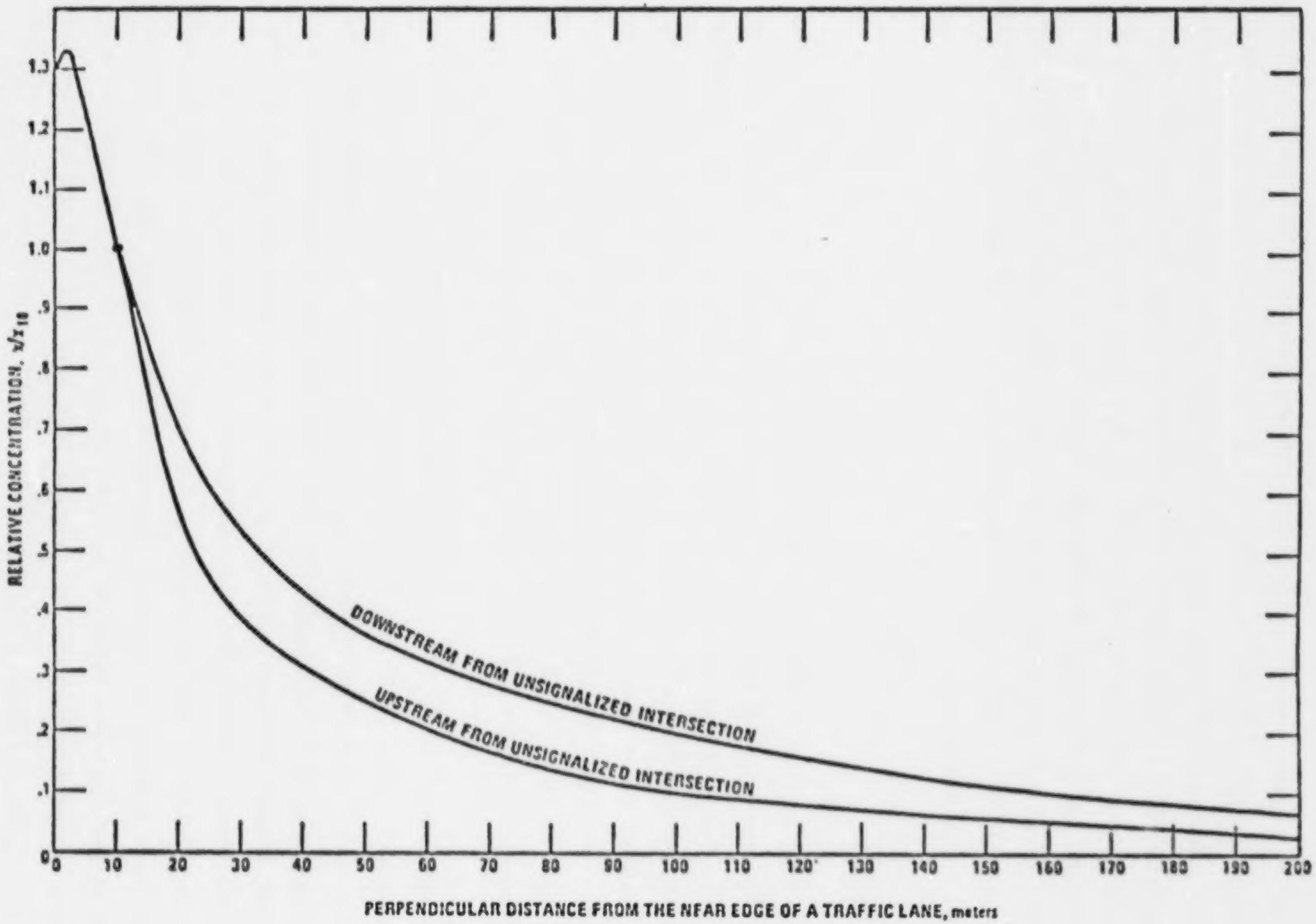


Figure 8. Relative concentration of CO versus perpendicular distance from a traffic lane near a nonsignalized intersection

from a stopped position. The critical direction is defined as the roadway direction with the highest average lane V/C. This is an appropriate method for consistency with other aspects of the Guidelines but may not be the most rigorous method available.

The Highway Capacity Manual states that the departure rate from an approach where all vehicles are stopped prior to entering the intersection, is, at most, about 1500 vehicles per hour. On the other hand, where no stops are required, the maximum flow rate is about 2000 vehicles per hour. This implies that vehicles stopped prior to entering an intersection use a larger increment of capacity than do moving vehicles, because of longer headways and slower average speeds occurring throughout the acceleration phase. Numerically, the implication is that one stopped vehicle entering a freely flowing stream is equivalent to $\frac{2000}{1500} = 1.33$ vehicles (with respect to capacity) already in the stream. Again, the concept developed for computing the approach capacity of a STOP-sign controlled street is that the capacity available is, simply, some factor times the "excess" capacity (capacity minus the actual volume demand) for the critical direction of the through street. The factor alluded to above, then, is an expression of the relative vehicular capacities of the two streets, in terms of equivalent vehicles. Stated differently, the factor expresses the observation that a vehicle entering a moving traffic stream because of its slower speed, etc., is equivalent to about 1.33 vehicles already in the stream with regard to its impact on capacity. In general terms, the approach capacity (C_2) of STOP-sign controlled street, is:

$$C_2 = \left(\frac{C_1 - V_1}{1.33} \right) \text{ or } C_2 = (0.75)(C_1 - V_1) \qquad (4)$$

where C_2 = capacity of STOP-sign controlled approach

C_1 = average lane capacity of the major street in the critical direction

V_1 = average lane volume of the major street in the critical direction

Analysis Results

Figures 5 and 7 were utilized to develop critical volumes for various configurations of STOP-sign controlled intersections, as shown in the guideline volume. Included are the following:

- 2-lane, 2-way, 4-way STOP (congested area)
- 2-lane, 2-way, 4-way STOP (noncongested area)
- 2-lane, 2-way minor; 2-lane major (congested area)
- 2-lane, 2-way minor; 2-lane major (noncongested area)
- 2-lane, 2-way minor; 4-lane major (congested area)
- 2-lane, 2-way minor; 4-lane major (noncongested area)
- 4-lane, 2-way minor; 4-lane major (congested area)
- 4-lane, 2-way minor; 4-lane major (noncongested area)
- 2-lane, 1-way minor; 2-lane major
- 2-lane, 1-way minor; 4-lane major

EFFECTS OF VARIATION IN PARAMETER ASSUMPTIONS

The analysis presented here was performed to investigate the sensitivity of the computed CO concentrations to changes in the input parameters for the screening curves. Assumptions for seven traffic and air quality parameters were required to compute the values for the plotting of the preliminary (first-stage) screening curves. These assumptions are tabulated in Table 1 for the analysis of a signalized intersection composed of a 4-lane/2-way roadway in a noncongested area which is crossed by a 2-lane/2-way facility (Screening Curve 6-B*).

The assumptions are based on estimates of generalized traffic and air quality relationships. The generalized relationships were devised from analyses of actual traffic operational characteristics of locations in the area of Waltham, Mass., and information from various texts such as the Highway Capacity Manual.[7]

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*See screening guideline volume.

Table 1. ASSUMPTIONS FOR CO CONCENTRATION COMPUTATIONS[a]

Parameter	Value assumed in screening curves
Lane volume split	40% - 60%
Directional volume split	50% - 50%
Roadway edge to receptor distance	2 meters
% ADT during peak hour	8.5%
Background concentration	5 ppm
Departure cruise speed	30 mph
8-hour correlation factor	0.70

[a] Analysis of a 4-lane/2-way roadway in a noncongested area crossed by a 2-lane/2-way roadway. Intersection is fully signalized.

The estimates for the parameters are regarded as producing an accurate model of the proposed generalized conditions. Since all estimates, however, are subject to some amount of uncertainty, a sensitivity analysis, discussed in the following text, helps in analyzing and understanding the effects of variations in the values of the control parameters.

The process selected for the sensitivity analysis was to vary one parameter at a time and recompute the CO concentration screening curve for that new set of parameters. The variations in the parameter values selected for use in the sensitivity analysis are listed in Table 2. Because estimates were required for seven parameters, the analysis was completed for seven sets of parameters.

Table 2. VARIATION IN ESTIMATED PARAMETER VALUES FOR SENSITIVITY ANALYSIS

Parameter	Value used in sensitivity analysis
Lane volume split	50% - 50%
Directional volume split	60% - 40%
Roadway edge to receptor distance	6 meters
% ADT during peak hour	7.5%
Background concentration	4 ppm
Departure cruise speed	15 mph
8-hour correlation factor	0.64

The results of the analyses show that the selected changes (Table 2) in the roadway-edge-to-receptor distance, the background concentration, and the 8-hour correlation factor parameters have the same numerical effect on the allowable volumes of the intersecting roadways. The other four parameters, for their selected changes, yield varying effects on allowable volumes. The basic screening curves and the seven variations are plotted on Figure 9 for comparison. The percentage variation in the allowable volumes are presented in Table 3, along with the differences in the parameter values.

Interpretation of the variation analysis results shows, for instance, that a 1.0 ppm reduction in the CO background concentration would yield a 15 percent increase in the allowable volumes. It is expected that a 1.0 ppm increase in the background concentration would decrease the allowable volumes by approximately 15 percent. This may not prove exact because the relationship between traffic volume and CO concentrations is not linear; however, for small incremental variations it can be assumed approximately linear. The intention of these statements is to stress that changes which can be either increases or decreases in the estimated values of each parameter can yield positive or negative changes

Table 3. CHANGES IN PARAMETERS VERSUS CHANGES IN ALLOWABLE VOLUMES

Parameter	Difference in value of parameter between screening curve assumption and sensitivity analysis[a]	Approximate change in allowable volumes, percent
Lane volume split	10%	- 5% on street of analysis - 20% on cross street
Directional volume split	10%	- 10%
Roadway edge to receptor distance	+ 4 meters	+ 15%
% ADT during peak hour	- 1%	+ 13%
Background concentration	- 1 ppm	+ 15%
Departure cruise speed	- 15 mph	- (10 to 20)%
8-hour correlation factor	- 0.06	+ 15%

[a] Differences between values in Table 1 and Table 2.

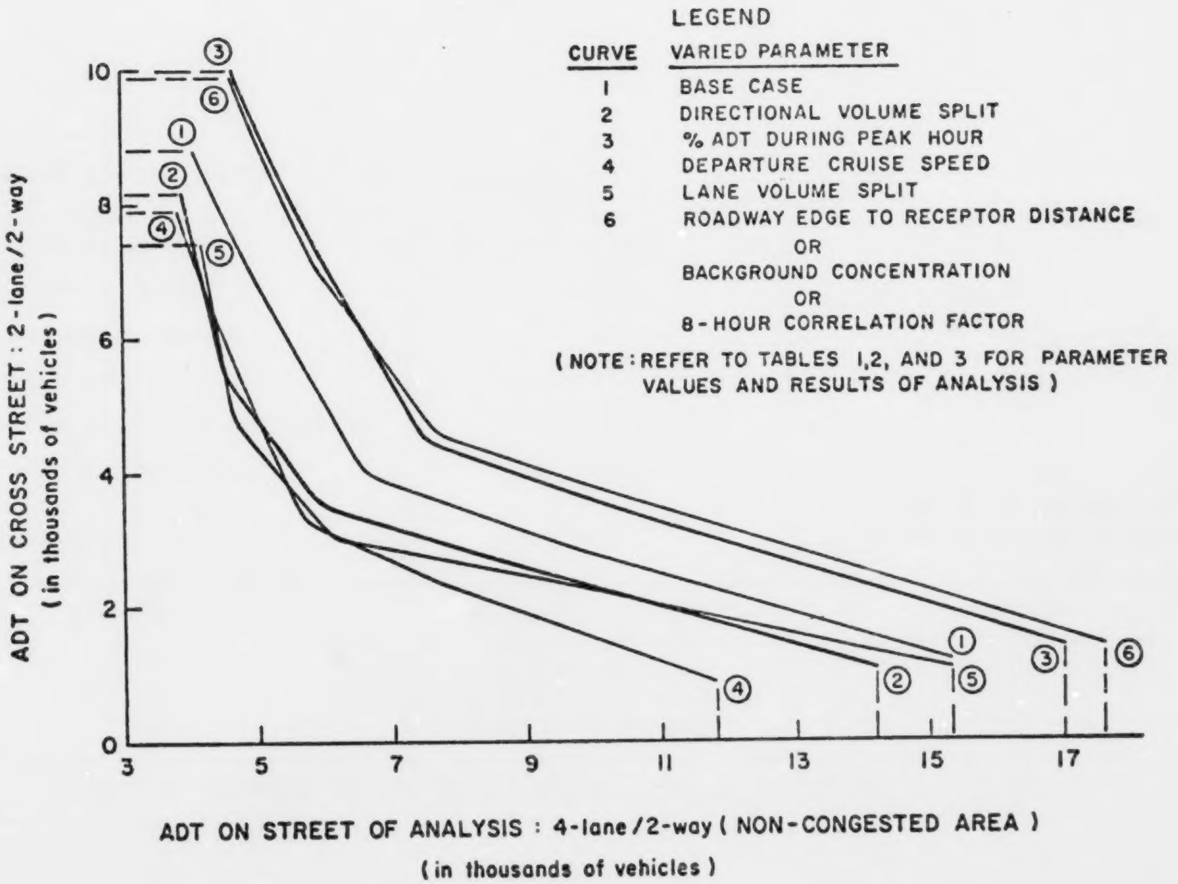

Figure 9. Examples of effects on screening curves of variations in parameter assumptions

in allowable volumes. In other words, each parameter can be varied to cause either reductions or increases in the resultant volumes.

The significance of this analysis of possible variations in the parameters is that it exhibits the effects on expected CO concentration of differences between the assumed conditions and conditions at an actual site. In addition, it shows the direction and relative magnitude of the effect on air quality of changes in site conditions that might be brought about through some of the control measures.

The results shown in Table 3 and plotted on Figure 9 exhibit the variations possible with example changes in the estimated values of the parameters. It is considered that the set of values for the generalized conditions listed in Table 1 yield satisfactory results for average conditions. Uncertainty in the use of these estimated values will undoubtedly occur at unusual or complex locations. The uncertainty for these special cases, however, would be eliminated during application of the second-stage analysis (i.e., the verification process).

EVALUATION

The screening guidelines, whose development has been described in this Section, were tested by applying them to Waltham, Massachusetts. Data collection, analysis, results, and comparison with second-stage screening are discussed in Section V.

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SECTION III

DEVELOPMENT OF PROCEDURES FOR VERIFYING HOT SPOT POTENTIAL

GENERAL

Background

This section describes the development of the guidelines for verification of potential hot spots of carbon monoxide concentrations. The guidelines themselves are presented in a separate volume.

Screening, as presented in the separate guidelines, is a two-part process. Development of the first part, preliminary screening, was described in Section II. Development of the second part, verification of hot spot potential, is described here.

Most of the text in this section was initially included in Technical Memorandum No. 3 (October 1975), issued during the project to document the research results.

Purpose of Verification

The verification process is a follow-up to the initial screening of an area. The intent is to perform a more precise evaluation of the hot spot potential of a street section or intersection utilizing a technique that permits input of parameters specific to that location rather than assumed parameters. Whereas the initial screening process focused on identification of potential hot spot locations anywhere within a city or town (therefore requiring a very general approach) the verification process involves analysis of specific locations; therefore a more detailed analysis of each location is feasible.

The technique involved is, conceptually, identical to that used for screening — that is, it is assumed that an explicit relationship exists between air quality and parameters such as traffic operating characteristics, and physical characteristics of an intersection, for particular meteorological conditions. Therefore, if both traffic and physical characteristics are determined and a particular set of meteorological conditions assumed, estimates of the resulting air quality can be made.

The empirical relationships (between air quality and the traffic and physical characteristics of a roadway) used in this analysis were developed for and are discussed in the Indirect Source Guidelines.[1] These relationships were modified slightly to reflect emission rates characteristic of 1977 when, according to provisions of the Clean Air Act, final compliance to the National Ambient Air Quality Standards becomes mandatory for all Air Quality Control Regions.

Evolution of the Verification Concept

At the outset of this project, analysis of CO hot spots was envisioned as a two-step process: screening and modeling. Development of the preliminary screening guidelines, originally intended to be the only screening guidelines, involved many assumptions and generalizations in order to achieve the simplicity that was desired. GCA/Technology Division considered that there was a possibility that these assumptions in the screening guidelines either would cause the guidelines to be overly conservative or would limit the utility of the screening guidelines. Thus, the test cases in Waltham, Mass., were reanalyzed with the Indirect Source Guidelines themselves and with local traffic data collected for that purpose.*

The application of the Indirect Source Guidelines to the Waltham study locations led GCA to the following conclusions:

- The preliminary screening guidelines are not overly conservative, as demonstrated by the fact that the preliminary screening guidelines identified only a few more potential hot spots in the Waltham case study than did the application of the more detailed Indirect Source Guidelines.+
- The Indirect Source Guidelines are a workable method for analysis of potential hot spots, and allow the use of more data specific to conditions at individual locations. Results are quantitative, rather than qualitative.
- The Indirect Source Guidelines can, in some cases, be used for assessment of alternative improvement measures, in lieu of modeling.

These conclusions led GCA to recommend the use of the Indirect Source Guidelines as the foundation for a second stage of screening. The verification guidelines are therefore an explanation of how to use the Indirect Source Guidelines for screening, and are not truly "new" in any developmental sense.

Content of This Section

The remainder of this section will present a description of how certain specific issues were resolved in the process of preparing the detailed verification guidelines. Because the verification guidelines are essentially the application of the Indirect Source Guidelines, there is no attempt here to discuss the development of the Indirect Source Guidelines or those aspects of their use that are straightforward.

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*Data collection for the Waltham case studies is described in Section V of this volume.

+Results of applying the two sets of guidelines are presented in Section V of this volume.

DISCUSSION OF SPECIFIC ISSUES

Adjustment for Vehicle Mix

Review of the Indirect Source Guidelines indicated that the emissions intensity/air quality relationships were developed utilizing an assumed vehicle population comprising 88 percent light-duty vehicles, and 12 percent light-duty trucks. This particular vehicle mix probably will not be representative of the actual vehicle mix in many cases; therefore appropriate correction factors are needed.

In deriving correction factors for various vehicle-type distributions several issues came to light that warrant discussion. First, in establishing emission factors, six vehicle classifications are generally considered, including: light-duty vehicles (LDV), light-duty trucks (LDT), heavy duty, gasoline-powered vehicles (HDV), motorcycles (MC), light-duty, diesel-powered vehicles (LDDV), and heavy-duty, diesel-powered vehicles (HDDV). However, in actually classifying moving vehicles, it is usually not possible to distinguish LDDV's from other light-duty vehicles; therefore this class of vehicles is not considered separately, but is included in the LDV classification. Secondly, since the winter season is of interest, motorcycles can also be omitted.* Thirdly, it may not be possible for some field classification personnel to distinguish all HDDV's from HDV's since there generally are not any totally reliable features that would be apparent to a classifier for distinguishing one type from the other. Determining the distribution of HDDV's within the general category of heavy trucks, then, may require estimates based on either observation by personnel capable of distinguishing between HDDV's and HDV's, or through vehicle registration data.

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*Guidelines were developed for initial use in the colder, northeastern states. Application elsewhere would alter this.

Vehicle-type distributions, then, from a practical standpoint, should focus on identifying LDV's, LDT's, HDV's, and HDDV's (if possible).

Obviously, the principal reason for identifying the vehicle-type distribution is that emissions characteristics vary substantially among vehicle types. However, not only do emission characteristics vary by vehicle-type, but also, significant variations in emission rates occur among different model years within the same vehicle-type classification. The implication here is that, in order to develop correction factors for vehicle-type distributions, consideration must be given to the age distribution within each vehicle-type category, as well. In this regard, data available from the Springfield, Massachusetts region, and the Hartford, New Haven, and Southwestern Connecticut regions were analyzed to determine relative emissions rates for the previously-mentioned vehicle types for a projected "average" vehicle age distribution as of 31 December 1977; this analysis is summarized in Table 4.

Considered in the development of the emission indices presented in the table are vehicle-age distribution, relative exposure (average annual vehicle-miles traveled) of each year vehicle, relative operating speeds of each model year, and the basic emission factors for each model year.

Considering the vehicle-type distribution assumed in the Indirect Source Guidelines (88 percent LDV's and 12 percent LDT's) it can be seen that for any hourly volume V_T, 0.88 V_T are LDV's while 0.12 V_T are LDT's. Applying the average emissions indices from Table 4 to this vehicle population over a distance of D_T miles, gives a value for total emissions burden of:

Table 4. EMISSION INDICES BY VEHICLE TYPE FOR THREE REGIONS

Vehicle type	Emissions index in grams per vehicle mile[a,b]			
	Springfield	Hartford	New Haven and SW Connecticut	Average[c]
LDV	17.8	24.4	25.4	22.5
LDT	33.2	36.7	38.2	36.0
HDV	106.0	116.7	121.3	114.7
HDDV	28.7	28.7	28.7	28.7

[a] Low altitude factors used.

[b] Indices developed by GCA during previous projects, using methods from AP-42.[2]

[c] This average was used only for determining a representative proportion of vehicle types and does not imply the use of the average speeds for these regions.

$$E_B = \left[(0.88\ V_t)(22.5) + (0.12\ V_T)(36.0)\right] D_T$$

or

$$E_B = \left[(0.88)(22.5) + (0.12)(36.0)\right] V_T D_T = 24.12\ V_T D_T$$

where E_B represents total emissions generated for the basic condition which is with regard to the vehicle-type distribution assumed in the Indirect Source Guidelines, and is, therefore, reflected in the emission intensity/air quality relationships presented in Figures 1, 2, 4, 5, and 7, and the corresponding figures in the guideline volume.

Now, if the same number of vehicles, V_T, are assumed to comprise a different type distribution, say, 80 percent LDV's, 10 percent LDT's, 8 percent HDV's, and 2 percent HDDV's, the total emissions, again, over a distance of D_T miles, can be expressed as follows:

$$E_A = \Big[(0.80\ V_T)(22.5) + (0.10\ V_T)(36.0) + (0.08\ V_T)(114.7) + (0.02\ V_T)(28.7)\Big] D_T$$

or

$$E_A = \Big[(0.80)(22.5) + (0.10)(36.0) + (0.08)(114.7) + (0.02)(28.7)\Big] V_T D_T = 31.35\ V_T D_T$$

where E_A represents the total emissions generated for the actual vehicle-type distribution of the roadway under analysis.

Assuming that, if all other conditions remain constant, air quality is proportional to emissions, the correction factor (f_{vm}) to be applied to Figures 1, 2, 4, 5, and 7, to account for differences between the overall emissions rate of the actual vehicle-type distribution, and the vehicle-type distribution assumed in the Indirect Source Guidelines, is:

$$f_{vm} = \frac{E_A}{E_B} = \frac{31.35\ V_T D_T}{24.12\ V_T D_T} = \frac{31.35}{24.12} = 1.30 \text{ in this example.}$$

A general equation, then, can be written that will describe the concentrations of carbon monoxide expected from any vehicle-type distribution, relative to the concentrations resulting from the vehicle-type distribution assumed in the Indirect Source Guidelines; this expression is:

$$\chi_c = \chi_v f_{vm} \qquad (5)$$

where χ_c is the expected concentration of carbon monoxide, corrected for local vehicle-type distribution.

χ_v is the total concentration resulting from nearby traffic computed from Figures 1, 2, 4, 5, or 7.

Also, the vehicle-type distribution correction factor, f_{vm}, can be expressed in general terms by:

$$f_{vm} = \frac{1}{24.12}\left[(\rho_{ldv})(i_{ldv}) + (\rho_{ldt})(i_{ldt}) + (\rho_{hdv})(i_{hdv}) + (\rho_{hddv})(i_{hddv})\right] \quad (6)$$

where ρ_{ldv} = percent LDV's in the vehicle population x 10^{-2}
ρ_{ldt} = percent LDT's in the vehicle population x 10^{-2}
ρ_{hdv} = percent HDV's in the vehicle population x 10^{-2}
ρ_{hddv} = percent HDDV's in the vehicle population x 10^{-2}
i_{ldv} = average emissions index for LDV's; = 22.5*
i_{ldt} = average emissions index for LDT's; = 36.0*
i_{hdv} = average emissions index for HDV's = 114.7*
i_{hddv} = average emissions index for HDDV's = 28.7*

The above formulation was thus incorporated in the verification guidelines.

Effects of Grades

An additional correction factor should be considered that would account for the effects of highway grades on emission characteristics. However, sufficient data was not available from research on this topic; therefore, it was not possible in this project to develop appropriate correction factors. This may warrant further investigation, given the obvious, large effect of grades on engine parameters.

Adjustment for Tail Pipe Controls

For areas where so-called "tail pipe controls" such as retrofit or inspection and maintenance are anticipated, adjustments should be applied accordingly to account for reduced emissions rates. Since these types of controls are often specific to a particular classification of vehicle, such as retrofitting only HDV's or applying inspection and maintenance to LDV's only, the adjustments should be applied only to the classification(s) affected. In applying the adjustments, the expected reduction in emissions (expressed in percent x 10^{-2}) attributable to the control measure is applied to the emissions index for the vehicle category affected. For instance, if a particular configuration of inspection and maintenance is expected to be applied to LDV's and LDT's only, and the expected reduction overall in emissions from each is 9 percent and 11 percent, the adjustments involved are:

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*See Table 4.

for LDV's: emissions index (i_{ldv}) from Table 4 is 22.5 grams/mile. Effectiveness of control measure is 9 percent x $10^{-2} = 0.09$. corrected emissions factor (i'_{ldv}) is:

$$i'_{ldv} = (i_{ldv})(1.0 - 0.09) = (22.5)(0.91) = 20.5 \text{ grams/mile.}$$

for LDT's: emissions index (i_{ldt}) from Table 4 is 36.0 grams/mile. Effectiveness of control measure is 11 percent x $10^{-2} = 0.11$. Corrected emissions factor (i'_{ldt}) is:

$$i'_{ldt} = (i_{ldt})(1.0 - 0.11) = (36.0)(0.89) = 32.0 \text{ grams/mile.}$$

To account for the effects of the inspection and maintenance, then, the emissions indices i'_{ldv} and i'_{ldt} are substituted for i_{ldv} and i_{ldt}, respectively, in Equation 6.

Accounting for Background

To estimate the total concentration occurring at a receptor an additional component - the background concentration - must be added to the corrected vehicular component. Various methods are suggested in the Indirect Source Guidelines for determining the background concentration for a particular area; however, these methods require a certain amount of short-term, local air quality monitoring and also assume that historical ambient air quality data are available from a permanent monitoring station within the general area of the site. Given the cost and time requirements for short-term monitoring, and the extent of current long-term air quality monitoring programs, it is highly unlikely that these procedures could be used in the context of hot spot verification. The alternative suggested here is to simply assume a value of 5 ppm to represent the maximum 1-hour average background concentration for all areas. This procedure is also suggested in the Indirect Source Guidelines for situations where monitoring is not feasible. It is stressed, however, that if data are available that permit derivation of the actual background concentration, then these derived values should be used rather than the assumed value of 5 ppm. Substantiation of the recommended value of 5 ppm is discussed in Section II.

Relationship Between 1-Hour and 8-Hour CO Concentrations

It has been discussed that the primary concern for most roadways is with regard to the maximum 8-hour average concentration of carbon monoxide. Therefore, the 1-hour average concentration computed by the procedure in the guidelines must be adjusted to reflect the expected 8-hour average concentration. An adjustment factor, P, has been developed through analyses of long-term quality data from several monitoring stations, as was discussed in Section II of this volume.

Selection of Cruise Speeds for Analysis of Signalized Intersection

It is necessary to determine cruise speed downstream of an intersection in order to compute concentrations in accordance with the Indirect Source Guidelines. For the verification guidelines it was desired to provide estimates of suitable speeds, to facilitate analysis where local data is not at hand. The recommended cruise speed ranges were correlated to general location types, based on engineering judgment. It is recognized that the criteria are somewhat subjective but they are only intended for use where better data is not available.

Selection of Receptor Sites

In order to use the Indirect Source Guidelines, or the hot spot verification guidelines that have been developed from them, it is necessary to identify the distance from the traffic to a reasonable receptor. Because the calculated ambient concentration of carbon monoxide is highly sensitive to the distance between source and receptor (e.g., refer back to Figure 3), it appears to be quite important to define what is a "reasonable receptor."

The Indirect Source Guidelines include some discussion[3] of how to select a reasonable receptor site. Rather than attempt to prepare a new interpretation of this difficult topic, GCA elected to merely reproduce, in the hot spot guidelines, a portion of the receptor site discussion from the Indirect Source Guidelines. For roadways, the essence of the reproduced guidance is to usually use the centerline of the adjacent sidewalk as the reasonable receptor site, which is reflected in the screening guidelines.*

GCA did not reproduce the entire text, however. The Indirect Source Guidelines recommend a procedure in which CO concentrations are averaged along the longitudinal direction of the sidewalk (that is, averaged along the sidewalk centerline, moving parallel to the roadway). The concept appears to be to reflect the fact that pedestrians normally move along a sidewalk and do not stand for long at one location. This averaging procedure would tend to indicate lower concentrations than would be indicated by considering only points near intersections. That is, in general one would expect CO peaks at locations near intersections and lower values at other points in a block.

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*Alternative procedures are recommended for cases without sidewalks.

GCA did not recommend this averaging procedure primarily because it seemed somewhat inconsistent with the concept of "hot spots," which by definition are worst-case situations. The averaging procedure would also require computations at many additional points, which would be cumbersome for screening.

It is considered that additional guidance on this topic is warranted (see also Section VI).

REFERENCES

1. Guidelines for Air Quality Maintenance Planning and Analysis. Volume 9: Evaluating Indirect Sources. U.S. Environmental Protection Agency, Research Triangle Park, N.C. Publication Number EPA-450/4-75-001. January 1975. 509 p.

2. Supplement No. 9 to Compilation of Air Pollutant Emission Factors, Second Edition. U.S. Environmental Protection Agency, Research Triangle Park, N.C. Draft, April 1975. Section 3.

3. Guidelines for Air Quality Maintenance Planning and Analysis, Volume 9, op. cit. pp. 11-13.

SECTION IV

DEVELOPMENT OF GUIDELINES FOR HOT SPOT MODELING AND FOR SELECTION OF CONTROL MEASURES

GENERAL

This section describes development of draft guidelines for modeling of hot spots and for selection of control measures contained in Appendices A and B of this volume. These guidelines are preliminary and require additional development and thus have not been included in the guideline volume.

To a large extent, there is little that was "developmental" about the guidelines on modeling and on selection of control measures. Rather, they present the application of GCA's experience with the modeling, analysis, and control of carbon monoxide. The guidelines themselves are largely self-explanatory and will not be elaborated upon here. Specific items will be commented upon, however.

DISCUSSION OF SPECIFIC ASPECTS OF MODELING GUIDELINES

In Appendix A, GCA has attempted to present a summary description of several alternative air quality models that can be used for analyzing CO from roadways. Those selected for discussion were considered practical and available. Because of the nature of the guideline, it was decided to present a summary, rather than to elaborate on models that are more fully described elsewhere.

Because this guideline is intended primarily for traffic and highway agencies, it was decided not to provide substantial discussions of traffic data collection. The guideline presumes the reader is either familiar with traffic engineering or would engage the services of a consultant or of an agency with traffic engineering expertise.

Data on costs were based upon GCA's experience, in particular with past air quality research and preparation of air quality planning reports.

DISCUSSION OF SPECIFIC ASPECTS OF SELECTING CONTROL MEASURES

Use of Previous Experience

Appendix B presents a digest of available traffic engineering techniques for controlling carbon monoxide levels. Much of the discussion was taken from the extensive existing literature on the potential of various control measures. Because most of the existing literature deals with the theoretical potential, GCA provided information on actual experience where possible.

One source of data on the application of control measures was GCA's experience with Transportation Control Plans (TCP's). In particular, APRAC results from two cities were used to provide quantitative examples of the effectiveness of control measures. Social, economic, institutional, and other types of implementation issues were described, again using concrete examples from GCA's recent TCP experience.

Another source of data was literature on traffic engineering improvements undertaken for the Federal TOPICS[*] program and their effect on traffic speed, volumes, and delay. Although not initiated for air quality control purposes, the example measures had the types of impact on traffic that are needed for reducing CO emissions. It was necessary for GCA to quantify the emissions reductions, using procedures that will be described next.

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[*] Traffic Operations Program to Improve Capacity and Safety.

Calculation of Emissions Reductions

Introduction - To provide quantitative estimates of the effects on air quality of the example traffic engineering measures, two computational techniques were used. The APRAC-1a model was used in the course of developing the TCP's for Providence, R.I., and Springfield, Mass., and results are presented in Appendix B. APRAC was used in a straightforward manner and will not be described further here.

Where new computations were made, GCA used a modified form of the Kircher and Armstrong technique. Guidelines for screening were not used because the data came from a secondary source that did not provide all the data needed for the use of the guidelines. As an example, the NCHRP report provided results in terms of speed and delay, and did not identify roadway capacity. Capacity data is needed for the guidelines, but the Kircher-Armstrong technique can use speed and delay data directly.

Procedure - Many models have been developed to analyze air quality improvements. For the determination of potential CO emission burden reductions due to traffic flow improvement programs the following algorithm was selected.

$$E_T = E_d + E_t \qquad (7)$$

where E_T = Total CO emission burden
E_d = CO emissions accountable to vehicular travel delays
E_t = CO emissions accountable to vehicular travel

and where E_d and E_t are calculated by the following:

$$E_d = \frac{V \cdot D \cdot ef_d}{60} \tag{8}$$

$$E_t = \frac{V \cdot T \cdot ef_s}{60} \tag{9}$$

where V = Volume

D = Average delay per vehicle (seconds)

T = Average travel time per vehicle (seconds)

ef_d = Emission factor for idling (gr/min)

ef_s = Emission factor for travel spped (gr/min)

The relationship states that emissions over time are the product of traffic volume, time spent within the area, and emission rate.

The emission rates used in the analyses are based on the following assumptions and data sources. The idling emission rate is calculated by assuming that an idling vehicle on the average emits carbon monoxide at the same rate as that vehicle emits traveling at the speed of 15.0 mph. This rate was calculated by adjusting the 1975 national average emission factor for 19.6 mph from AP-42,[1] a value of 61.1 grams/veh-mi, for the speed of 15.0 mph. A convenient speed correction factor curve was provided in the 1973 version of AP-42.[2] The value of 1.26 was suggested for 15 mph. To verify the use of the older adjustment factor curve, the adjustment for 15 mph was also determined from the adjustment formula in the current version of AP-42,[3] namely:

$$V_{ips} = e^{(A+BS+CS^2)} \tag{10}$$

for which the data is shown in Table 5. The 1973 value of 1.26 is reasonably consistent with the newer data. Thus the chosen emission factor for idling (and for speeds between 0 and 15 mph) is:

Table 5. CALCULATION OF EMISSION RATE CORRECTION FACTOR FOR 15 MPH

Vehicle type	LDV and LDT[3]			HDV[4]
Vehicle model year	1969	1970	1971-72	1970-72
Factors				
A	1.259	1.267	1.241	1.047
B	-0.0772	-0.0772	-0.0752	-0.0652
C	0.00066	-0.00064	-0.000609	0.000601
Correction Factor, V_{ips}[a]	1.28	1.29	1.28	1.23

[a] $V_{ips} = e^{(A+BS+CS^2)}$ from equation 10.

$$61.1 \text{ gr/mi} \times 1.26 = 77.0 \text{ gram/mi}$$

This rate was then converted to 19.25 grams/minute, by multiplying by the speed (15 mph) and dividing by the number of minutes in an hour. As a result of this verification of the older version of AP-42, it was also used for other speeds.

Results of the emission computations are presented in Appendix B.

APPLICATION OF HOT SPOT PLANNING CONCEPTS TO WALTHAM

In order to illustrate the planning process for control of CO hot spots, a preliminary analysis was undertaken of two alternative control measures for Waltham, Mass. This example planning process was based upon traffic engineering improvements previously recommended for Waltham by others. (The example improvements had been recommended for traffic purposes, not CO control).

This example analysis is not complete for evaluating these alternatives for Waltham; more data collection and more extensive analysis would be needed. Nonetheless, this example will serve to illustrate the planning processes and identify the types of issues that arise.

The following presentation is consistent with the sequence recommended in Section I of the guideline volume, except that steps 7 (Implementation) and 8 (Evaluation) are omitted.

Screening (Steps 1 and 2)

The City of Waltham was screened as described in Section V. For this example, two intersections (out of 51 locations that were screened) will be analyzed. The design characteristics of the two intersections and the screening results are listed in Table 6. Both intersections are in

Table 6. EXISTING CHARACTERISTICS OF EXAMPLE INTERSECTIONS IN WALTHAM, MASS.[a]

No.	Intersection: leg[b]	Description	Curb parking	Roadway width (m)	G/Cy[c]	ADT[e] (1977-78)	Estimated 8-hour average CO concentration (winter 1977-78)[f] (ppm)
7	Main St. at Lexington St.						
	Main St. (East)	4-lane two-way	North side	19	0.65	20,000	15.0
	Main St. (West)	4-lane two-way	Both side	19	0.70 0.49[d]	20,000	15.0
	Lexington St. (North)	2-lane two-way	East side	9	0.24	10,000	15.4
13	School St. at Lexington St.						
	Lexington St. (North)	2-lane two-way	None	9	0.53	14,000	13.7
	Lexington St. (South)		East side	9	0.53	10,000	11.1
	School St. (East)		None	8	0.33	8,000	10.7
	School St. (West)		North side	10	0.33	9,000	11.4

[a] Refer to Table 13 through Table 18 and Figure 10 in Section V for traffic characteristics at these sites.

[b] Refer to Figure A-1a and A-1b in Appendix A of the guideline volume for location of sites in Waltham.

[c] From Table 19.

[d] Left turn movement only.

[e] Refer to Figure A-3a and A-3b in Appendix A of the guideline volume for Traffic Flow Map of Waltham.

[f] From Figure 10.

NOTE: Sketches of these intersections are among those included in Appendix C.

the heart of the Waltham Central Business District. Maps are in Appendix A of the guideline volume, and location sketches are in Appendix C of this volume.

Screening showed that both intersections will have the potential to violate CO standards in 1977 with calculated 8-hour average CO levels of up to 15.4 ppm at the Main/Lexington intersection and up to 13.7 ppm at the School/Lexington intersection. (The 8-hour standard is 9.0 ppm.)

Detailed Modeling (Step 3)

Modeling has not been done for this area and was not possible within the effort for the present project. Because of the number of potential hot spots, the Waltham CBD would be an appropriate location to be modeled with a method such as APRAC that can be run simultaneously for multiple locations. The present example analysis will use the verification screening process for the purposes of evaluating alternative improvements, a procedure that is offered in the guidelines as a workable approach for certain locations.

The screening guidelines suggest determining the amount of emission reduction required from traffic controls as a guide for planning. Using the data in Table 6, the necessary degree of emissions reduction can be determined from the linear rollback formula:

$$\text{Percent reduction required} = \left[1 - \frac{c_{std} - c_b}{c_{local}}\right] \times 100 \qquad (11)$$

where c_{std} = Allowable concentration (National Ambient Air Quality Standard)

c_b = Background concentration

c_{local} = Portion of concentration caused by local sources to be controlled

The term c_{local} is found from

$$c_{local} + c_b = c_{total} \tag{12}$$

where c_{total} = Calculated (or measured) total concentration

so that

$$c_{local} = c_{total} - c_b \tag{13}$$

Table 7 shows the necessary data for solving equation (11) for the present two examples, and shows the maximum reduction required at each intersection. Here, no adjustments are made for tail pipe controls because inspection/maintenance was already considered in the screening. Table 7 shows that the Main/Lexington intersection needs a reduction in emissions of 54 percent, and School/Lexington needs 46 percent. To illustrate the relative severity of this requirement, consider that volumes would have to be reduced by roughly one half in order to achieve the required emission reduction by volume changes alone. If speed and delay improvements can also be made, then the volume reduction would not have to be so great. (Also, note that both locations would violate CO standards even if there were no contribution from background.)

Table 7. CALCULATION OF REQUIRED REDUCTION IN AUTOMOTIVE EMISSIONS FOR EXAMPLE CASES

Intersection	Maximum present CO level, c_{total}[a]	Background CO level, c_b	CO level from local sources, c_{local}[b]	Reduction required percent[c]
Main St. @ Lexington St.	15.4	3.5	11.9	54%
School St. @ Lexington St.	13.7	3.5	10.2	46%

[a] Highest leg from Table 6. Calculated 8-hour average level.

[b] $c_{local} = c_{total} - c_b$

[c] Reduction required = $\left[1 - \frac{c_{std} - c_b}{local}\right] \times 100$. $c_{std} = 9$ ppm. Quantity is reduction required from traffic controls alone.

Identification of Alternative Improvements (Step 4)

For this exercise, two alternatives were analyzed. Both of these alternatives were previously proposed by others as solutions to traffic problems in Waltham. These were not originally planned as CO control measures, but are among the types of control measures identified for consideration in Appendix B.

Description of Alternative No. 1: Waltham Center Bypass - Main Street (U.S. Route 20) is the principal east-west arterial within the City of Waltham, Massachusetts, and as such currently must accommodate 20,000 or more vehicles each day. Since there is considerable local traffic interspersed with through traffic because of the intense commercial nature of the area, a condition of almost continuous congestion occurs as many drivers seek alternate or bypass routes to avoid Main Street. The possibility of utilizing a portion of existing Boston and Maine Railroad right-of-way north of Main Street as a highway bypass has been recommended by a consultant to the Massachusetts Department of Public Works.[5] (Refer to Figures A-1a and A-1b in Appendix A of the guideline volume for location of this railroad right-of-way.)

The recommended bypass of Waltham Center would use the Boston and Maine Railroad right-of-way (South Sudbury Branch) and would be connected at its west end directly to Route 128 at the Weston Street rotary interchange, and at its east end to Linden Street. The plan recommended that the existing railroad tracks be relocated to the north side of the right-of-way and that a 2-lane, two-way roadway be constructed to carry all vehicle types, with at-grade signalized intersections with the local street system at Linden Street, Middlesex Circle, Lyman Street, Lexington Street, Bacon Street, Hammond Street, Prospect Street, Main Street (west), and Stow Street. All signalized intersections would be coordinated to provide for efficient traffic flow. Left-turn storage lanes would be provided at all intersections. Pavement markings, signing, and roadway lighting would also be provided as required. Traffic volumes are estimated to average 10,000 to 12,000 vehicles per day throughout the length of the bypass.

The bypass would significantly improve the operation of the signalized intersections of Main Street with Lexington Street and School Street with Lexington Street. Traffic flow would be improved because of significant decreases in volumes ranging from 33 percent to 60 percent, as shown in Table 8. A synergetic effect would occur due to the elimination of through trucking on these portions of Main, Lexington and School Streets. Trucks on fairly level terrain are the equivalent of approximately two to five passenger cars depending on exact grade and level of service. In addition, signal phasing and timing can be readjusted to optimize capacity and traffic flow at the new operating conditions.

Table 8. RELATIVE TRAFFIC VOLUMES WITH PROPOSED IMPROVEMENT PROGRAMS, WALTHAM

	Relative traffic volumes		
Intersection: street	Existing,[a] percent	Proposed bypass,[a] percent	Proposed TOPICS program,[a] percent
Main St. @ Lexington St.			
Main St.	100	67	80
Lexington St.	100	40	80
School St. @ Lexington St.			
School St.	100	50	120
Lexington St. (South of School St.)	100	40	80
Lexington St. (North of School St.)	100	40	100

[a] Volumes expressed as a percentage of winter 1977-78 estimated volumes.

Descriptions of Alternative No. 2: Waltham TOPICS Program - TOPICS programs (Traffic Operations Program to Increase Capacity and Safety) began in 1967 providing for the use of federal-aid highway funds for the application of traffic engineering improvements to major urban roadways. TOPICS programs typically apply basic traffic engineering theory, recommending such improvements as the channelization of intersections, roadway widening, additional approach lanes at signalized intersections, signalization and circulation adjustments, placement of latest traffic control devices and elimination of spot safety hazards. The intent of the program is to obtain optimum use of existing facilities at maximum cost effectiveness.

A consultant to the Massachusetts Department of Public Works had recommended traffic engineering improvements for approximately 50 locations in the city of Waltham.[6] Included in this group are the signalized intersections of Main Street with Lexington Street and School Street with Lexington Street.

The recommended improvements begin with establishing Lexington Street as one way from School Street to Main Street, a roadway length of approxicimately 600 feet. The one-way operation of this street would force circulation changes in the area, decreasing volumes on Main and Lexington Streets with offsetting increases on School Street, as shown in Table 8. In conjunction with these changes, the other legs at the School Street and Lexington Street intersection would be widened to provide two-lane approaches. Other improvements at both intersections would include replacement of signal equipment and adjustment of signal phasing and timing.[7]

Evaluation of Alternatives (Step 5)

Each of the two alternatives were analyzed for their air quality effects, using the verification guidelines. Qualitative review of other issues will also be presented here; a more extensive analysis would be needed in an actual application.

Evaluation of Alternative No. 1: Waltham Center Bypass - Air quality and other issues will be discussed separately.

Air quality - The proposed bypass would divert substantial traffic away from Main Street and thus would reduce both traffic volumes and congestion at both of the intersections. According to the consultant's report, volumes would be reduced by 33 percent on Main Street, 50 percent on School Street, and 60 percent on Lexington Street. (Determination of these volume changes was based upon a traffic redistribution process, which requires origin-destination data.)

In connection with the volume changes, traffic signal timing would be adjusted accordingly. In addition, the vehicle mix factor would be altered considerably, because much of the present truck traffic (LDT and HDV) would be diverted to the bypass.

These effects on traffic were summarized in Table 8. Table 9 shows calculated effect on air quality. Both intersections are seen to be improved considerably, with reductions in CO levels of from 31 to 45 percent. The Main/Lexington intersection would require more detailed analyis, because one leg is shown to experience a CO level just equal to the standard. Also, the intersection at Main and Lexington is seen to be affected more than that at School and Lexington, but the former was also originally somewhat worse for CO levels.

It should be noted that construction of the bypass would create nine new at-grade intersections between the bypass and existing streets. Each of these would have to be planned so that new hot spots are not created. Being able to plan for control of CO from the start should allow a satisfactory design, however.

Table 9. EFFECT OF EXAMPLE ALTERNATIVE IMPROVEMENTS ON CO LEVELS AT TWO LOCATIONS IN WALTHAM

	Existing	Proposed bypass		Proposed TOPICS program	
Intersection: leg	CO concentration,[a] ppm	CO concentration,[a] ppm	Change, %	CO concentration,[a] ppm	Change, %
Main St. @ Lexington St.					
Main St. (east)	15.0	8.8	-41%	9.9	-34%
Main St. (west)	15.0	9.0	-40%	10.6	-29%
Lexington St. (north)	15.4	8.5	-45%	15.5	+ 1%
School St. Lexington St.					
Lexington St. (north)	13.7	8.9	-35%	14.9	+ 9%
Lexington St. (south)	11.1	7.5	-32%	7.1	-36%
School St. (east)	10.7	7.4	-31%	11.6	+ 8%
School St. (west)	11.4	7.6	-33%	12.3	+ 8%

[a] Estimated 8-hour average CO concentration for winter 1977-78.

Other impacts - This (preliminary) presentation of non-air-quality impacts is based upon the categories used in Appendix B.

Social impacts of the bypass (those impacts that affect individuals) would include several positive aspects. Such a bypass would reduce traffic congestion, and thus reduce time spent in travel for all those who travel through the area. Safety and amenity are also expected to improve for the population as a whole, although some specific individuals may be adversely affected by their nearness to the new bypass. Improvement would be particularly noted in the downtown business and retail districts, where reduced automobile traffic would result in less noise, fumes, and hazard to pedestrians.

The consultant's report[5] evaluated the road user costs and benefits for several alternative bypass designs. Taking into account (1) vehicle running costs, (2) stopping costs (costs associated with intersection delays, for instance), and (3) accident costs, the estimated annual benefits to road users ranged between $832,000 and $1,393,000.* For the particular alternative that was recommended, the net annual road user monetary benefits were estimated to be $1,258,000.

One possible social impact of the bypass that warrants further investigation is the effect on transit service. At present, there are several different bus routes that pass along Main Street and several that use Lexington Street. Reducing traffic on Main Street or Lexington Street would presumably improve travel speed for buses and thus improve the transit service. In addition, however, it may be possible to divert some buses to the bypass itself, thus providing express-type service that avoids downtown Waltham.

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*Based upon 1972 conditions.

There are some possible adverse social consequences of the bypass. Traffic on the bypass may produce increased noise, air pollution, and danger to residents adjacent to the right-of-way, and may adversely affect nonresidential types of activities as well. Furthermore, construction would probably produce other environmental impacts, including increased water pollution and similar problems. To fully address these potential issues, which may or may not be substantial, a standard environmental assessment would be required. Such an assessment should include a land use survey, noise analysis, and macroscale air pollution analysis.[*]

Economic impacts of the bypass would include several aspects. First, there would be substantial monetary construction costs. The consultant's report estimated costs that ranged between $3.6 million and $6.0 million for the various alternatives; cost of the recommended alternative would be $4.5 million. Using 1972 data, the consultant estimated the annualized costs to be $406,000.[+] It can be presumed that a substantial fraction of the construction cost could be from Federal highway funds, although the specific availability of such funds remains to be investigated.

Other economic impacts might include some effect on business activity in Waltham center. Businessmen often object to highways bypassing an existing shopping district, on the theory that through traffic contributes to local sales but would be lost if the through traffic is diverted. In most cases where investigations have been undertaken, bypasses have been shown to have positive effects on local business.[8]

One argument for a positive effect on business is that the reduced traffic congestion makes the area more accessible and more attractive to those whose trip purpose is shopping, and thus may increase the number of trips deliberately destined for the area.

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[*] It is entirely possible that a bypass would increase macroscale (regional) pollutant burden even though CO hot spots would be improved.

[+] Based upon 1972 prices, 20-year analysis period, and 6 percent interest.

In spite of the general positive experience with bypasses, one would expect the question to arise and opposition to develop. Only a detailed economic study, performed in connection with the environmental review, and careful interaction with the community can resolve this issue.

There may also be institutional impacts of a bypass. The need to coordinate with many community officials and groups is obvious, but is also routine for planning such projects. One special problem will be careful coordination with the railroad, whose tracks must be relocated. Service disruptions would occur and must be minimized. Also, the merchants' interests must be resolved, as mentioned earlier. Otherwise, the institutional problems will be similar to those with other highway projects.

Macroscale travel impacts would occur with the bypass, but have been analyzed and are reflected in the predicted traffic volumes in the consultant's report.

Evaluation of Alternative No. 2: Proposed TOPICS Program - Again, each of several aspects will be discussed separately, following the framework of Appendix B.

Air quality - Traffic volumes would be affected by the TOPICS program because of the effect of making Lexington Street one-way. As shown in Table 8, traffic volumes would decrease by 20 percent on Main Street and on part of Lexington Street, but would increase on School Street. Timing of traffic signals would be adjusted, and other improvements would be made as described earlier. These changes would generally reduce CO levels adjacent to two legs of the Main/Lexington intersection, but the leg with the highest CO level (15.4 ppm on Lexington Street) is actually made slightly worse (to 15.5 ppm), as shown in Table 9. The School/Lexington intersection is generally made slightly worse, because of increased volumes, with a new highest CO level of 14.9 ppm. Thus, no hot spots would actually be eliminated by this alternative, although it could probably be shown that total person exposure would be reduced because of the considerably lower levels on two legs of Main Street.

The TOPICS project would also affect air quality at other locations, which would be reviewed in a full analysis.

Other impacts - This preliminary analysis will follow a sequence similar to that for Alternative Number 1.

No quantitative estimate has been made of the social impacts of the TOPICS improvement. It would be expected to improve travel speeds in the immediate vicinity of the improvement and thus slightly reduce road-user costs. Reduced hazards should benefit both drivers and pedestrians, although some increase in hazard may occur on School Street because of the increased travel volumes.

No other substantial environmental impacts are envisioned, because of the minor nature of the improvements. (No detailed environmental or economic study is normally performed for routine traffic engineering improvements of this nature, although such a study may be warranted if a comprehensive program were planned for the entire central portion of Waltham.)

The primary economic impacts would be the direct construction costs. The consultant's report[7] estimated these to be $50,000 for the Central Square Area (including the Main/Lexington intersection) and $30,000 for the School/Lexington intersection.*

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*1971 estimates.

A minor economic impact could result from removal of four curb parking spaces in front of the bank on Main Street just west of Lexington Street. The existance of a parking lot behind the bank and a recommendation for additional parking on Lexington Street should tend to minimize the possibility of any adverse effects on business. (Nonetheless, Waltham merchants have generally expressed opposition to removal of curb parking elsewhere on Main Street, out of a fear that business would be adversely affected.)

Institutional impacts of the improvements at these two intersections would be expected to be minor. But other aspects of the proposed improvements to the Central Square Area have produced substantial institutional-political difficulties. Opposition from merchants has arisen, primarily because of the proposed elimination of some curb parking spaces in the vicinity of Elm and Church Streets. Consequently city officials have declined to approve the plan. The Massachusetts Department of Public Works evidently will not proceed without city agreement. An aspect of this worth noting is that there is a deadline after which Federal funds earmarked for this project will be diverted to other projects if funds are not committed before the deadline.

Because of the localized nature of the projects, macroscale travel impacts would be expected to be minor.

Selection of Control Measures (Step 6)

At this point, one would normally have evaluated more alternatives than have been presented here. Nonetheless, comparison of these two actual alternatives is useful.

Alternative No. 1, the bypass, would virtually eliminate the two hot spots being examined, although additional analysis is needed to verify that. On the other hand, it produces substantial impacts. Most notably perhaps, it would involve major construction cost ($4.5 million) and associated disruption. Because of the substantial user benefits, the bypass appears to be warranted from a classical economic viewpoint: the consultant calculated a benefit/cost ratio of 3.10 for the recommended design.*

Alternative No. 2, the TOPICS project, would cost much less ($80,000), be much less disruptive, and produce much less other environmental impact. Unfortunately, it is also not very effective at eliminating the two particular hot spots that were examined. (The overall TOPICS plan may be effective in controlling CO for other locations not analyzed here.)

Thus, the choice between these two, solely on an air pollution basis, would be to build the bypass. In a more practical sense, however, one would examine additional alternatives, and examine them in greater detail, before deciding upon a hot spot control measure.

This example does illustrate several points, however.

- Control of CO hot spots in congested business areas will often require more than routine traffic engineering measures. Traffic redistribution or traffic restraints will need serious consideration for 1977-78 attainment, if traffic control techniques are to be relied upon.
- Analysis and planning of alternative CO controls requires skills in traffic engineering, air pollution control, and environmental assessment, because of the complex nature of the problem.
- Specifically for Waltham, additional analysis and planning work is needed before workable CO hot spot control measures can be selected.

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*1972 data and 6 percent interest rate, as stated earlier.

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SECTION V

DATA COLLECTION IN WALTHAM

GENERAL

Data collection for the Waltham case study occurred in two phases, the screening and the verification stages. This section will identify the data requirements and sources.

Fifty-one locations in Waltham were selected for preliminary screening, using the procedures now in Sections II and III of the guideline volume. The results of the first stage (screening) indicated that 37 locations were either potential hot spots or special cases requiring a more detailed analysis to determine their hot spot potential. The second-stage analysis (verification) of these 37 locations revealed potential violations at 30 locations. The analyses are summarized below.

Location type	Number screened	Number analyzed by verification process	Number with potential CO violations according to verification process
Signalized intersections	31	27	26
Nonsignalized intersections	13	7	2
Uninterrupted flow	7	3	2
Totals	51	37	30

The above tabulation indicates, qualitatively, the agreement between the first-stage (screening) and second-stage (verification) analyses as they were applied to Waltham. Thirty-seven locations were deemed to be potential hot spots by the first review, and 30 by the second, out of a total of 51 locations. There are at least two factors that account for the difference in number of potential hot spots between the two stages.

For one, the first-stage analysis was done for Waltham with a preliminary version of the screening guidelines that were based upon 1975 to 1976 conditions. Specifically, the Indirect Source Guidelines curves were used directly, and they are based upon 1975 emission factors. In contrast, the second-stage analysis used the 1977 curves presented in Section II. One would expect fewer locations with violations in 1977 than in 1975, because of new, less-polluting vehicles entering the population.

Second, the second-stage analysis accounted for the effect of inspection/maintenance of light duty vehicles, which is due to be implemented in Massachusetts by 1977. This would also tend to reduce the number of locations with violations.

Even without these two factors, both of which tend to produce greater violations in 1975 than in 1977, there would be likely to be variations in the results of the two steps, because the second stage analysis used new, more refined data.

Thus, the Waltham application of the second-stage screening tends to confirm the reasonableness of the screening guidelines.

The field testing program was performed in the City of Waltham, Massachusetts, by GCA/Technology Division personnel. The program involved collecting and compiling basic traffic data, analyzing these traffic data, evaluating the hot spot potential of each location utilizing the techniques described in the guidelines, and, finally, recording the results of the analysis.

One point must be emphasized regarding the field testing program in Waltham - the primary objective was to evaluate the workability of the procedures for hot spot identification as outlined in the screening guidelines. In light of this objective as well as time constraints encountered during the project, excessive emphasis was not placed on assuring the accuracy of traffic data collected. In addition, because the field testing in Waltham proceeded in parallel with the development of the technique, refinements were often not incorporated in analyses that had already been performed. The implication intended is that during data collection in Waltham more latitude was allowed for "engineering judgment" than would normally be prudent in the conduct of a traffic study, owing to the fact that the issues perceived as being of primary importance concerned the evaluation of the technique rather than the actual results of the analysis.

PRELIMINARY SCREENING DATA REQUIREMENTS AND SOURCES

This section will present the data as it was collected for the Waltham screening analysis. In addition, the sources of the data will be acknowledged. The required data is typically obtainable quite easily for the cities and towns in the Metropolitan Boston area. The estimated effort to collect and prepare the data is approximately 1 man-week over a calendar period of about 2 weeks by a single person, for the city of Waltham.

Table 10 outlines the data requirements and the sources utilized. As can be seen by this table a great percentage of the data was collected and compiled from pre-existing sources. A field inspection trip was required only to make note of general operating and physical conditions required in the selection and use of the preliminary screening curves. It is expected, however, that local highway officials familiar with the operation of the roadways in the community would be able to provide this information for the preliminary screening process.

Table 10. DATA REQUIREMENTS AND SOURCES FOR WALTHAM SCREENING

Data requirements	Sources
1. City street map for location siting	
a. Street location familiarity	A
b. Federal Aid Highway System	A
c. Signal locations	A,B,C
2. Traffic volume data	
a. Traffic flow map (or volumes by street segments)	A,D
b. Yearly travel growth factors	G,D
c. Monthly traffic variation factors	I
3. Roadway operations	
a. Number of operating lanes	F,A
b. General physical characteristics	F,E
4. Highway capacities	
a. Lane - (uninterrupted flows)	H,E,F
b. Intersection - (unsignalized intersection)	H,F

Note: A = Areawide TOPICS Reports
B = MDPW Signal Permits
C = City Highway Agency
D = MDPW Volume Count Data Bank
E = MDPW Roadway Inventories
F = Field Reconnaissance
G = National Transportation Study
H = Highway Capacity Manual
I = Insufficient Data (further study required)

As described in the screening guidelines, the data required and collected for Waltham include the following. Traffic volume data was obtained from the 1972 Waltham Areawide TOPICS Plan report. The report contained a traffic flow map which had been updated by applying the appropriate yearly growth factors. This report aided in gaining the familiarity with the local roadway system including designated federal-aid highways and signal locations in the city.

The data supplied by the TOPICS report was updated and complemented by the use of signal permits, volume counts and roadway inventories from the resources of the Massachusetts Department of Public Works. In addition, as mentioned previously, a field inspection provided first hand knowledge of actual roadway operations.

This data adequately provided the information required to select the locations to be screened, to select the proper screening curve and to use the screening curve for the preliminary screening analysis.

In summary, a total of 51 locations were included in the preliminary screening. These locations are listed in Table 11 and are shown in Figures A-1(a) and A-1(b) in the guideline volume. The entire preliminary screening process took less than 1.5 man-weeks of effort and netted results indicating the necessity for further analysis of 37 locations.

TRAFFIC DATA COLLECTION PROGRAM

The verification of hot spot potential at the 37 locations in which further analysis was indicated from the preliminary screening required a specific data for development of various adjustment factors as described in the guidelines. The 37 locations are listed in Table 12 and are shown in Figures A-1(a) and A-1(b) in Appendix A of the guideline volume.

Identified in the guidelines are a number of individual data elements necessary for verifying the hot spot potential of a location. Included were

Table 11. LOCATIONS IN WALTHAM SCREENED FOR HOT SPOT POTENTIAL

I. Signalized intersections:

1. Main Street/Warren Street
2. Main Street/Gore Street
3. Main Street/Linden Street
4. Main Street/Newton Street
5. Main Street/Appleton Street
6. Main Street/Elm Street/Church Street
7. Main Street/Lexington Street
8. Main Street/Moody Street
9. Main Street/Bacon Street
10. Main Street/Prospect Street
11. Main Street/Weston Street
12. Weston Street/Eddy Street
13. Lexington Street/School Street
14. Lexington Street/Trapelo Road
15. Lexington Street/Totten Pond Road
16. Moody Street/Maple Street/High Street
17. Moody Street/Carter Street
18. Bacon Street/Dale Street
19. Bacon Street/School Street
20. Trapelo Road/Smith Street
21. Beaver Street/Waverly Oaks Road
22. Hammond Street/Columbus Street
23. Summer Street/Lyman Street
24. Willow Street/Grove Street
25. Newton Street/River Street
26. South Street/Vernon Street
27. Prospect Street/Felton Street
28. Maple Street/Adams Street
29. High Street/Lowell Street
30. High Street/Newton Street
31. Trapelo Road/Waverly Oaks Road

II. Nonsignalized intersections:

32. Main Street/Lyman Street
33. Trapelo Road/Forest Street
34. Beaver Street/Forest Street
35. Lexington Street/Lake Street
36. Moody Street/Pine Street/Crescent Street
37. Moody Street/Crescent Street/Derby Street
38. Beaver Street/Linden Street
39. Waverly Oaks Road/Linden Street
40. Lyman Street/Church Street
41. Prospect Street/Charles Street
42. Prospect Street/Crescent Street
43. Lexington Street/Beaver Street
44. Weston Street/South Street

III. Midblock locations:

45. Route 128 between Main Street and Weston Street
46. Trapelo Road between Waverly Oaks Road and Forest Street
47. Weston Street between Route 128 and Eddy Street
48. South Street between Highlands Street and Brandeis University
49. Beaver Street between Forest Street and Waverly Oaks Road
50. Moody Street between Derby Street and High Street
51. Totten Pond Road between Route 128 and Lexington Street

Table 12. LOCATIONS IN WALTHAM ANALYZED FOR VERIFICATION OF HOT SPOT POTENTIAL

I. Signalized intersections

1. Main Street/Warren Street
2. Main Street/Gore Street
3. Main Street/Linden Street
4. Main Street/Newton Street
5. Main Street/Appleton Street
6. Main Street/Elm Street/Church Street
7. Main Street/Lexington Street
8. Main Street/Moody Street
9. Main Street/Bacon Street
10. Main Street/Prospect Street
11. Main Street/Weston Street
12. Weston Street/Eddy Street
13. Lexington Street/School Street
14. Lexington Street/Trapelo Road
15. Lexington Street/Totten Pond Road
16. Moody Street/Maple Street/High Street
17. Moody Street/Carter Street
19. Bacon Street/School Street
20. Trapelo Road/Smith Street
21. Beaver Street/Waverly Oaks Road
25. Newton Street/River Street
26. South Street/Vernon Street
27. Prospect Street/Felton Street
28. Maple Street/Adams Street
29. High Street/Lowell Street
30. High Street/Newton Street
31. Trapelo Road/Waverly Oaks Road

II. Nonsignalized intersections:

33. Trapelo Road/Forest Street
34. Beaver Street/Forest Street
36. Moody Street/Pine Street/Crescent Street
37. Moody Street/Crescent Street/Derby Street
40. Lyman Street/Church Street
42. Prospect Street/Crescent Street
44. Weston Street/South Street

III. Midblock locations:

45. Route 128 between Main Street and Weston Street
46. Trapelo Road between Waverly Oaks Road and Forest Street
47. Weston Street between Route 128 and Eddy Street

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traffic volume data, physical (roadway) data, traffic control data, vehicular mix data and others. These data were obtained during the Waltham field study for each location in Table 12, as is discussed in the following text.

Traffic Volume Data

Traffic volume data were established for each location through field counts taken during September 1975. Included were 108 manual 1-hour coverage counts, 11 24-hour automatic traffic recorder (ATR) counts, and one long-term control count taken at or in the vicinity of the locations listed in Table 12 and shown in Figures A-2(a) and A-2(b).* The manual counts were expanded to a 24-hour average daily traffic (ADT) volume based on the hourly distribution of traffic determined by the ATR counts. The distribution of traffic is shown in Table 13 for the 12 ATR locations. A traffic flow map which shows the computed ADT's for the City of Waltham is included in Appendix A as Figures A-3(a) and A-3(b).*

From these data, peak-hour volumes for each locations were then computed as a percentage of the 24-hour volume. The peak hour volumes were based on the traffic distribution of the nearest appropriate ATR count. Table 14 presents the assignments of the analysis sites to the traffic distributions of the 12 ATR's. In addition, the manual counts were taken so that both lane and directional distributions could be determined.

Future ADT's (for 1977) were estimated by factoring the current ADT's according to projected growth rates for various highway classifications, reported in the Federal Highway Administration's 1974 National Transportation Study for the Boston metropolitan area. These growth factors are presented in Table 15 below. The assigned Waltham Roadway Classification is presented in Table 16.

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*Refers to figures in Appendix A of the guideline volume.

Table 13. TRAFFIC DISTRIBUTION AT ATR LOCATIONS, WALTHAM

				Traffic distribution by hour of day														
				Hour ending														
No.	ATR location	Date	ADT	1-7	8	9	10	11	12	13	14	15	16	17	18	19	20	21-24
1	Lexington St. N/O Totten Pond Rd.	9/22-23/75	22,000	4.0	6.6	6.2	4.9	4.6	5.5	6.1	6.8	6.5	6.9	8.1	8.4	6.8	6.8	11.8
2	Trapelo Rd. E/O Lexington St.	9/22-23/75	15,000	4.2	7.0	7.9	5.0	4.7	5.5	6.5	5.9	6.2	7.2	8.6	8.8	5.8	5.1	12.0
3	Beaver St. E/O Forest St.	9/22-23/75	14,000	5.3	6.9	6.5	4.4	4.2	6.8	6.9	7.1	8.1	8.3	9.1	7.6	5.7	4.3	8.8
4	Main St. E/O Bowker St.	9/23-24/75	15,000	7.4	5.8	6.0	4.8	5.6	6.4	7.2	5.6	6.6	7.4	7.4	6.6	5.8	5.2	12.4
5	Lexington St. S/O School St.	9/23-24/75	10,000	5.3	5.0	6.1	5.8	6.4	6.2	6.9	6.4	6.4	6.5	6.5	6.4	6.0	5.9	13.9
6	River St. E/O Newton St.	9/24-25/75	13,000	6.5	6.4	5.4	5.5	5.2	6.3	7.0	6.8	7.3	7.1	6.5	6.5	5.5	5.4	12.5
7	High St. E/O Moody St.[a]	9/24-25/75	10,000	5.4	5.9	6.3	5.0	5.4	5.9	6.2	6.0	6.6	7.4	7.9	8.0	6.0	5.1	12.6
8	Moody St. N/O Pine St.	9/24/75	16,000	5.5	3.8	5.8	5.5	6.4	6.9	7.3	7.2	6.7	6.4	6.3	5.9	5.4	6.0	14.4
9	Prospect St. S/O Felton St.[a]	9/25-26/75	13,000	6.1	5.5	6.1	5.4	5.3	6.3	7.4	6.7	6.4	6.9	7.5	7.2	6.4	5.3	11.0
10	Weston St. E/O Eddy St.	9/25-26/75	14,000	6.6	5.8	6.6	5.6	5.7	5.9	5.9	6.0	5.9	7.2	7.3	7.2	5.9	4.5	13.9
11	Main St. W/O Harvard St.[b]	9/25-26/75	20,000															
12	Main St. W/O Newton St.	9/24/75	22,000	7.1	6.2	6.1	5.3	5.7	5.9	5.9	6.0	6.5	6.8	6.6	6.5	5.8	5.5	13.8

[a] Estimated due to machine operation problem.

[b] Data invalid due to machine breakdown.

Table 14. TRAFFIC DISTRIBUTION CLASSIFICATION OF HOT SPOT SITES

ATR location used as reference	1 Lexington St. N/O Totten Pond Rd.	2 Trapelo Rd. E/O Lexington St.	3 Beaver St. E/O Forest St.	4 Main St. E/O Bowker St.	5 Lexington St. E/O School St.
Hot spot sites assigned to each reference location	Lexington St. @ Trapelo Rd. Lexington St. @ Bacon St. Trapelo Rd. @ Smith St.	Trapelo Rd. @ Waverly Oaks Rd. Forest St. @ Trapelo Rd. Trapelo Rd.	Beaver St. @ Waverly Oaks Rd. Forest St. @ Beaver St. Lymon St. @ Church St.	Main St. @ Warren St. Main St. @ Gore St.	Lexington St. @ School St.

6 River St. E/O Newton St.	7 River St. E/O Moody St.	8 Moody St. N/O Pine St.	9 Prospect St. S/O Felton St.	10 Weston St. E/O Eddy St.	11 Main St. W/O Harvard St.	12 Main St. W/O Newton St.
Newton St. @ River St.		Moody St. @ Maple & High Sts. Moody St. @ Carter & Felton Sts. Moody St. @ Pine & Crescent Sts. Moody St. @ Crescent & Derby Sts.	Prospect St. @ Felton St. Maple St. @ Adams St. High St. @ Lowell St. High St. @ Newton St. Crescent St. @ Maple & Prospect Sts.	Main St. @ Prospect St. Main St. @ Weston St. Weston St. @ Eddy St. South St. @ Vernon St. Weston St. @ South St. Weston St.		Main St. @ Linden St. Main St. @ Newton St. Main St. @ Appleton St. Main St. @ Church & Elm St Main St. @ Lexington St. Main St. @ Moody St. Main St. @ Bacon St. Bacon St. @ School St.

NOTE: Route 128 peak hour volume estimated as 11 percent of its ADT.

Table 15. PROJECTED GROWTH RATES FOR TRAFFIC ON VARIOUS HIGHWAY CLASSES — 1972 to 1980

Highway classification	Annual growth rate factor[a]
Interstate	1.039
Principal arterials	1.005
Minor arterials	1.018
Collectors	1.049
Local	1.020

[a] Source — Federal Highway Administration's National Transportation Study for 1974

Table 16. WALTHAM ROADWAY CLASSIFICATION

Streets by roadway functional classifications				
Local	Collector	Minor arterials	Principal arterials	Freeways
Appleton St.	Wyman St.	Totten Pond Rd.	Main St.	Route 128
Common St.	Smith St.	Beaver St.	Weston St.	
Cabot St.	Lincoln St.	River St.	Lexington St.	
Adams St.	Lake St.	Linden St.	Moody St.	
Lowell St.	Forest St.	Waverly Oaks Rd.	Trapelo Rd.	
Derby St.	Lyman St.	Newton St.		
	Church St.	Grove St.		
	Warren St.	Prospect St.		
	Gore St.	Maple St.		
	Pine St.	High St.		
	Highlands St.	Vernon St.		
	Charles St.	Stow St.		
	Hammond St.	Eddy St.		
	Columbus St.	Carter St.		
		School St.		
		South St.		
		Elm St.		
		Bacon St.		
		Felton St.		
		Crescent St.		

Data on the seasonal variation in traffic were obtained from the Massachusetts Department of Public Works, Bureau of Transportation Planning and Development. However, from the data available, specific, consistent seasonal variations in ADT could not be detected; therefore it was decided not to adjust the ADT's computed above for seasonal (winter) variations. The final ADT's used for each location will be presented later.

Vehicle Classification Data

Vehicle classification counts were performed on seven streets in Waltham. Four vehicle classes were identified including: light-duty vehicles (LDV), light-duty trucks (LDT), heavy-duty, gasoline-powered vehicles (HDV), and heavy-duty, diesel-powered vehicles (HDDV). Table 17 provides a summary of the distribution for each street studied.

Table 17. VEHICLE-TYPE DISTRIBUTION FOR VARIOUS STREET CLASSIFICATIONS IN WALTHAM

Street	Classification	Vehicle distribution in percent			
		LDV	LDT	HDV	HDDV
Route 128	Expressway	81	11	5	3
Main Street	Principal Arterial	78	11	6	5
Moody Street	Arterial; principal shopping street	88	10	1	1
Crescent Street	Collector	90	6	4	0
High Street	Collector/minor arterial	86	10	3	1
Newton Street	Collector/minor arterial	82	14	3	1
Prospect Street	Minor arterial	84	10	5	1

Because classification counts were not taken for each street at each location, it was necessary to classify the streets by the existing classification counts. The vehicle-type distribution classification for the remaining streets in Waltham is presented in Table 18. Included at the bottom of the table is the calculated Vehicle Type Distribution adjustment factor as described in the guidelines.

Physical Data

A field review was made of each location listed in Table 12 and various characteristics of each were recorded. Specifically, the following data elements were noted:

1. Lane use - the number and use of all lanes was recorded including travel, parking, shoulder, and turn lanes.
2. Lane widths - the total width of each lane, shoulder, median or traffic island was recorded; also, restrictions in lateral clearance were noted.
3. Reasonable receptor sites - reasonable receptors on each side of all streets were identified and the distance from them to the edge of the roadway, determined.
4. General observations - general observations were recorded of any peculiarities of the location itself or of the operating characteristics; pedestrian activity and interference to free turns (if any), the presence of bus stops or taxi stands, general terrain features and adjacent land use and density were also noted.

A sketch of each location was drawn including the material identified above. The sketches of the 37 locations are presented as Appendix C to this volume.

Traffic Control Data

Traffic control data were compiled for all intersections listed in Table 12. The Massachusetts Department of Public Works and the City of

Table 18. VEHICLE TYPE DISTRIBUTION CLASSIFICATION

	Locations of vehicle type classification counts						
	Main St.	Prospect St.	Moody St. (S)	Crescent St.	High St.	Newton St.	Route 128
Streets using each reference location	Weston Lexington	River Linden (S) Waverly Oaks (S) Maple Smith	Vernon School South Forest Lyman Church Linden (N) Common Cabot Adams Lowell Derby	Eddy Hammond Columbus	Trapelo Beaver Carter Warren Gore Moody (N) Smith Waverly Oaks (N)	Totten Pond Bacon Elm Pine Highlands Felton	
Vehicle type adjustment factor[a]	1.16	1.10	0.95	1.04	1.02	1.04	1.11

[a] Includes a 9 percent adjustment in LDV's and LDT's for Inspection and Maintenance.

Waltham provided copies of traffic signal permits for all signalized intersections analyzed. These permits contained all required phasing and timing data as well as information regarding the type of controller utilized. As mentioned previously, field checks were made to determine certain operational characteristics of the signal installation such as the usage of pedestrian phases and interference to free turns.

The green time apportioned per cycle (G/Cy) for the signalized intersections as stated was available from the signal permits of each location. The G/Cy values at each location, required as explained in the guidelines, were computed and are presented in Table 19.

Conclusions

The time and effort required to complete the verification stage of the hot spot analysis for the 37 locations in Waltham is estimated to be approximately 5 to 6 man-weeks. This time is split as 3.0 to 3.5 man-weeks for data collection, 1.0 to 1.5 man-weeks for data compilation and 1.0 to 1.5 man-weeks to complete the hot spot verification process.

The final result of the preliminary screening and hot spot verification analyses indicate the potential exists for CO concentrations in violation of the 8-hour average NAAQS at 30 locations in Waltham. These 30 locations are listed in Table 20.

Figure 10 is a reproduction of the summary tabulation of the verification analysis, and tabulates the calculated CO concentrations for each location.

Complete work sheets for every location (of the types shown in the guidelines) screened in Waltham were reproduced in Technical Memorandum No. 4 (October 1975) and provided to a limited distribution. These are not reproduced here, owing to their bulk. Work sheets for 14 of these locations are included in the guideline volume (Appendixes B and C) as examples of the screening procedures.

Table 19. SIGNALIZED INTERSECTIONS G/Cy APPORTIONMENT

Location	Approach[a]	G/Cy
1. Main St. @ Warren St.	Main St. W/B	0.38
	Main St. E/B	0.38
	Warren St.	0.56[b]
		0.11[c]
2. Main St. @ Gore St.	Main St. W/B	0.82
		0.41[c]
	Main St. E/B	0.38
	Gore St.	0.11
		0.41[b]
3. Main St. @ Linden St.	Main St. W/B	0.47
	Main St. E/B	0.79
		0.27[c]
	Linden St.	0.27[b]
		0.14[c]
4. Main St. @ Newton St.	Main St. W/B	0.66
	Main St. E/B	0.71
	Newton St.	0.22
5. Main St. @ Appleton St.	Main St. W/B	1.00
	Main St. E/B	0.76
	Appleton St.	0.16
6. Main St. @ Elm St.	Main St. W/B	0.47
	Main St. E/B	0.72
		1.00[b]
	Elm St.	0.22
	Church St.	0.22
7. Main St. @ Lexington St.	Main St. W/B	0.65
	Main St. E/B	0.70
		0.49[c]
	Lexington St.	0.24
8. Main St. @ Moody St.	Main St. W/B	0.71
		0.18[c]
	Main St. E/B	0.50
	Moody St.	1.00[b]
		0.22[c]
	Common St.	0.22
9. Main St. @ Bacon St.	Main St. W/B	0.70
	Main St. E/B	0.75
	Bacon St.	0.18
10. Main St. @ Prospect St.	Main St. W/B	0.66
	Main St. E/B	0.62
	Prospect St.	0.26
	Hammond St.	0.18
11. Main St. @ Weston St.	Main St. W/B	0.62
	Main St. E/B	0.27
	Weston St.	1.00[b]
		0.62[c]
12. Weston St. @ Eddy St.	Weston St.	0.68
	Eddy St.	0.23
	Cabot St.	0.23
13. Lexington St. @ School St.	Lexington St.	0.53
	School St.	0.33
14. Lexington St. @ Trapelo Rd.	Lexington St. S/B	0.51
	Lexington St. N/B	0.51
		1.00[b]
	Trapelo Rd.	0.38
15. Lexington St. @ Totten Pond Rd.	Lexington St. S/B	0.30[c]
	Lexington St. N/B	0.61
		0.30[c]
	Bacon St.	0.16
	Totten Pond Rd.	0.37[c]
		0.06[b]

Table 19 (continued). SIGNALIZED INTERSECTIONS G/Cy APPORTIONMENT

Location	Approach[a]	G/Cy
16. Moody St. @ Maple St. @ High St.	Moody St.	0.50
	Maple St.	0.38
	High St.	0.38
17. Moody St. @ Carter St.	Moody St. S/B	0.62
	Moody St. N/B	0.41
	Carter St.	0.32
		0.45[b]
19. Bacon St. @ School St.	Bacon St.	0.45
	School St.	0.35
20. Trapelo Rd. @ Smith St.	Trapelo Rd.	0.42
	Smith St.	0.42
21. Beaver St. @ Waverly Oaks Rd.	Beaver St. W/B	0.45
	Beaver St. E/B	0.35
	Waverly Oaks S/B	0.45
		1.00[b]
	Waverly Oaks N/B	0.45
25. Newton St. @ River St.	Newton St.	0.47
	River St.	0.36
26. South St. @ Vernon St.	South St.	0.54
	Vernon St.	0.34
27. Prospect St. @ Felton St.	Prospect St.	0.56
	Felton St.	0.32
	Highlands St.	0.32
28. Maple St. @ Adams St.	Maple St.	0.60
	Adams St.	0.24
29. High St. @ Lowell St.	High St.	0.62
	Lowell St.	0.27
30. High St. @ Newton St.	High St. W/B	0.46
		1.00[b]
	High St. E/B	0.46
	Newton St.	0.43
31. Trapelo Rd. @ Waverly Oaks Rd.	Trapelo Rd. W/B	0.78
		0.39[c]
	Trapelo Rd. E/B	0.39
	Waverly Oaks	1.00[b]
	-	0.12[c]

[a] "Approach" here refers to the direction of traffic. The "W/B" approach is the East Leg, with westbound traffic. The term "leg" is used in some other tabulations.

[b] Right turn movement only.

[c] Left turn movement only.

Source: Signal permits filed with the Massachusetts Department of Public Works.

Note: G/Cy were not computed for location numbers 18, 22-4 because they did not require analysis for hot spot verifications.

Table 20. LOCATIONS IN WALTHAM WITH HOT SPOT POTENTIAL

I. Signalized intersections:

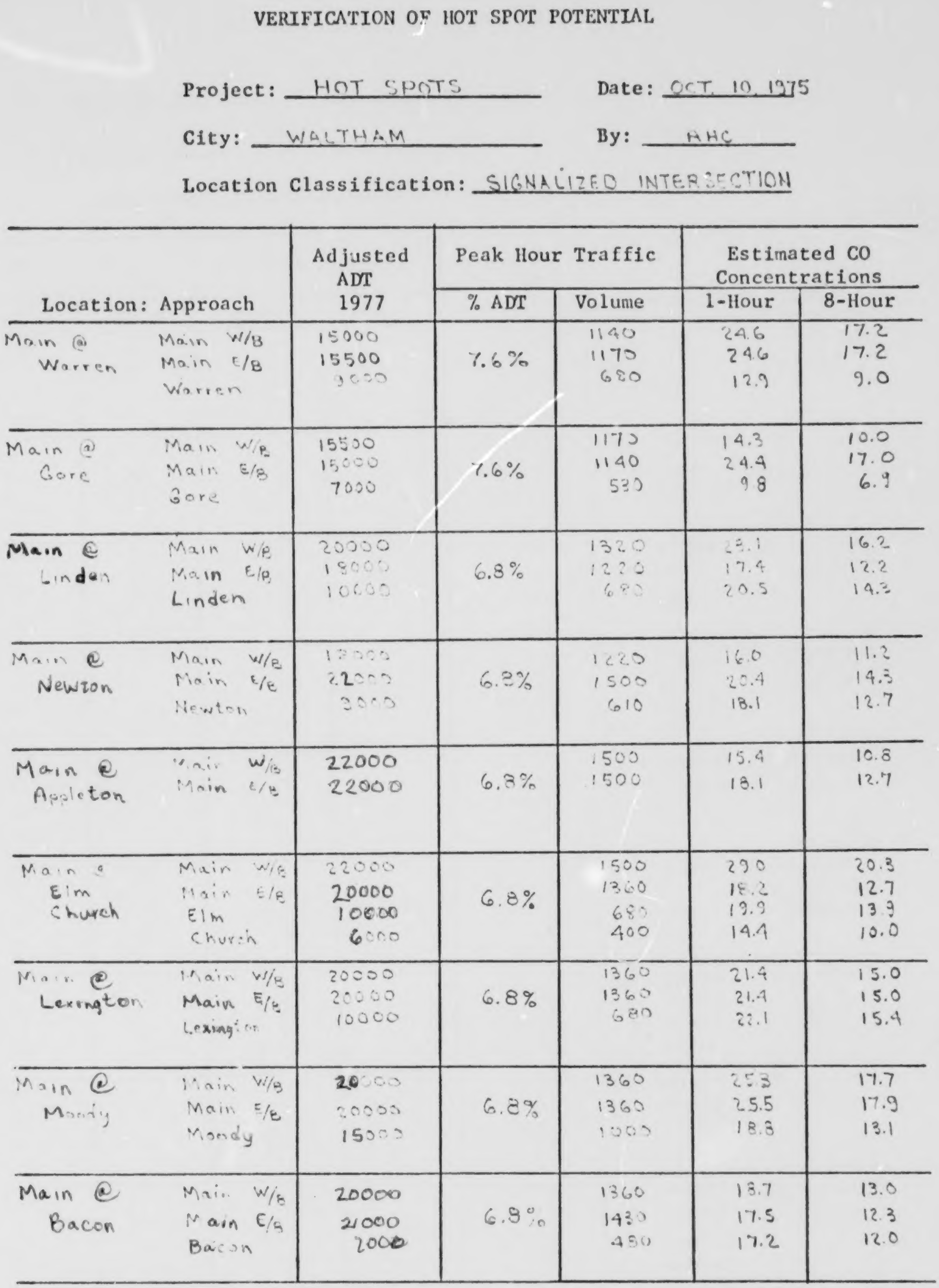
1. Main St. @ Warren St.
2. Main St. @ Gore St.
3. Main St. @ Linden St.
4. Main St. @ Newton St.
5. Main St. @ Appleton St.
6. Main St. @ Elm St. & Church St.
7. Main St. @ Lexington St.
8. Main St. @ Moody St.
9. Main St. @ Bacon St.
10. Main St. @ Prospect St.
11. Main St. @ Weston St.
12. Weston St. @ Eddy St.
13. Lexington St. @ School St.
14. Lexington St. @ Trapelo Rd.
15. Lexington St. @ Totten Pond Rd.
16. Moody St. @ Maple St. & High St.
17. Moody St. @ Carter St.
19. Bacon St. @ School St.
20. Trapelo Rd. @ Smith St.
21. Beaver St. @ Waverly Oaks Rd.
25. Newton St. @ River St.
26. South St. @ Vernon St.
27. Prospect St. @ Felton St.
28. Maple St. @ Adams St.
30. High St. @ Newton St.
31. Trapelo Rd. @ Waverly Oaks Rd.

II. Nonsignalized intersections:

36. Moody St. @ Pine St. & Crescent St.
37. Moody St. @ Crescent St. & Derby St.

III. Midblock locations:

45. Route 128 between Main St. and Weston St.
47. Weston St. between Route 128 and Eddy St.



VERIFICATION OF HOT SPOT POTENTIAL

Project: HOT SPOTS
Date: OCT. 10, 1975
City: WALTHAM
By: AHC
Location Classification: SIGNALIZED INTERSECTION

Location: Approach		Adjusted ADT 1977	Peak Hour Traffic		Estimated CO Concentrations	
			% ADT	Volume	1-Hour	8-Hour
Main @ Warren	Main W/B	15000	7.6%	1140	24.6	17.2
	Main E/B	15500		1170	24.6	17.2
	Warren	9000		680	12.9	9.0
Main @ Gore	Main W/B	15500	7.6%	1170	14.3	10.0
	Main E/B	15000		1140	24.4	17.0
	Gore	7000		530	9.8	6.9
Main @ Linden	Main W/B	20000	6.8%	1320	23.1	16.2
	Main E/B	18000		1220	17.4	12.2
	Linden	10000		680	20.5	14.3
Main @ Newton	Main W/B	18000	6.8%	1220	16.0	11.2
	Main E/B	22000		1500	20.4	14.3
	Newton	9000		610	18.1	12.7
Main @ Appleton	Main W/B	22000	6.8%	1500	15.4	10.8
	Main E/B	22000		1500	18.1	12.7
Main @ Elm Church	Main W/B	22000	6.8%	1500	29.0	20.3
	Main E/B	20000		1360	18.2	12.7
	Elm	10000		680	19.9	13.9
	Church	6000		400	14.4	10.0
Main @ Lexington	Main W/B	20000	6.8%	1360	21.4	15.0
	Main E/B	20000		1360	21.4	15.0
	Lexington	10000		680	22.1	15.4
Main @ Moody	Main W/B	20000	6.8%	1360	25.3	17.7
	Main E/B	20000		1360	25.5	17.9
	Moody	15000		1000	18.8	13.1
Main @ Bacon	Main W/B	20000	6.8%	1360	18.7	13.0
	Main E/B	21000		1430	17.5	12.3
	Bacon	2000		450	17.2	12.0

Figure 10. Reproduction of summary tabulation, hot spot verification analysis, Waltham

VERIFICATION OF HOT SPOT POTENTIAL

Project: HOT SPOTS
Date: OCT. 10, 1975
City: WALTHAM
By: AHC
Location Classification: SIGNALIZED INTERSECTION

Location: Approach		Adjusted ADT 1977	Peak Hour Traffic		Estimated CO Concentrations	
			% ADT	Volume	1-Hour	8-Hour
Main @ Prospect	Main W/B	20000	7.3%	1460	22.4	15.7
	Main E/B	22000		1600	23.2	16.2
	Prospect	11000		800	23.2	16.2
Main @ Weston	Main W/B	24000	7.3%	1750	22.4	15.7
	Main E/B	13000		950	25.4	17.8
	Weston	17000		1250	11.5	8.1
Weston @ Eddy	Weston W/B	14000	7.3%	1020	14.7	10.3
	Weston E/B	21000		1530	18.9	13.2
	Eddy	6000		440	17.2	12.0
Lexington @ School	Lexington S/B	14000	6.5%	910	19.6	13.7
	Lexington N/B	10000		650	15.9	11.1
	School W/B	8000		520	15.3	10.7
	School E/B	[illegible]		590	16.3	11.4
Lexington @ Trapelo	Lexington S/B	16000	8.4%	1340	[illegible]	15.8
	Lexington N/B	18000		1510	20.3	14.2
	Trapelo W/B	15000		1260	23.8	16.7
	Trapelo E/B	16000		1340	[illegible]	16.8
Lexington @ Totten Pond Bacon	Lexington S/B	23000	8.4%	1930	39.7	27.7
	Lexington N/B	22000		1850	28.5	20.0
	Bacon	10000		840	23.2	16.2
	Totten Pond	14000		1180	23.2	16.2
Moody @ Maple High	Moody S/B	11000	7.3%	800	15.5	10.9
	Moody N/B	11000		800	15.4	10.8
	Maple	9000		660	16.7	11.7
	High	10000		730	16.2	11.3
Moody @ Carter	Moody S/B	15000	7.3%	1100	17.0	11.9
	Moody N/B	15000		1100	22.7	15.9
	Carter	[illegible]		660	16.2	11.3
Bacon @ School	Bacon S/B	8000	6.8%	540	[illegible]	9.2
	Bacon N/B	7000		480	12.1	8.5
	School W/B	8000		540	13.7	9.6
	School E/B	8000		540	13.7	9.6

Figure 10 (continued). Reproduction of summary tabulation, hot spot verification analysis, Waltham

Reproduced from best available copy.

VERIFICATION OF HOT SPOT POTENTIAL

Project: HOT SPOTS   Date: OCT. 10, 1975

City: WALTHAM   By: AHG

Location Classification: SIGNALIZED INTERSECTION

Location: Approach		Adjusted ADT 1977	Peak Hour Traffic		Estimated CO Concentrations	
			% ADT	Volume	1-Hour	8-Hour
Trapelo @ Smith	Trapelo W/B	15,000	8.5%	1280	20.5	14.3
	Trapelo E/B	15000		1280	20.5	14.3
	Smith S/B	6000		510	12.2	8.6
	Smith N/B	6000		510	12.2	8.6
Beaver @ Waverly Oaks	Beaver W/B	12000	9.0%	1080	20.6	14.9
	Beaver E/B	12000		1080	22.7	15.9
	Waverly Oaks S/B	10000		900	11.1	7.7
	Waverly Oaks N/B	7000		630	14.9	10.4
Newton @ River	Newton S/B	12000	7.3%	880	16.2	11.3
	Newton N/B	17000		1240	20.6	14.4
	River W/B	16000		1170	22.9	16.0
	River E/B	11000		800	18.6	13.0
South @ Vernon	South S/B	10000	7.3%	730	12.9	9.0
	South N/B	9000		660	12.3	8.6
	Vernon W/B	6000		440	7.2	5.0
	Vernon E/B	6000		440	17.0	11.9
Prospect @ Felton	Prospect S/B	16000	7.5%	1200	20.3	14.2
	Prospect N/B	13000		980	17.8	12.5
	Felton	6000		450	18.9	13.2
	Highlands	6000		450	14.3	10.0
Maple @ Adams	Maple W/B	9000	7.5%	680	13.1	9.2
	Maple E/B	9000		680	13.1	9.2
High @ Lowell	High W/B	10000	7.5%	750	12.8	8.9
	High E/B	10000		750	12.8	8.9
High @ Newton	High W/B	14000	7.5%	1050	15.6	10.9
	High E/B	10000		750	15.3	10.7
	Newton S/B	11000		820	16.6	11.6
Trapelo @ Waverly Oaks	Trapelo W/B	15000	8.8%	1320	21.7	15.2
	Trapelo E/B	22000		1940	22.9	16.0
	Waverly Oaks	10000		880	9.6	6.7

Figure 10 (continued). Reproduction of summary tabulation, hot spot verification analysis, Waltham

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VERIFICATION OF HOT SPOT POTENTIAL

Project: HOT SPOTS
Date: OCT. 10, 1975
City: WALTHAM
By: AHC
Location Classification: NONSIGNALIZED INTERSECTIONS

Location: Approach		Adjusted ADT 1977	Peak Hour Traffic		Estimated CO Concentrations	
			% ADT	Volume	1-Hour	8-Hour
Trapelo @ Forest	Trapelo	15000	8.8%	1320		
	Forest	5000		440	7.5	5.3
Beaver @ Forest	Beaver	15000	9.1%	1360		
	Forest	7000		640	8.3	5.8
Moody @ Crescent Pine	Moody S/B	16000	7.3%	1170	18.5	13.0
	Moody N/B	11000		806	14.4	10.1
	Crescent	10000		730	17.8	12.5
	Pine	7000		510	14.6	10.2
Moody @ Crescent Derby	Moody S/B	11000	7.3%	800		
	Moody N/B	15000		1100		
	Crescent	9000		660	20.4	14.3
	Derby	4000		300	7.6	5.3
Lyman @ Church	Lyman S/B	9000	9.0%	800		
	Lyman N/B	6000		540		
	Church	5000		450	9.0	6.3
Prospect @ Crescent	Prospect	16000	7.5%	1200		
	Maple	9000		680		
	Crescent S/B	7000		520	9.2	6.4
	Crescent N/B	9000		680	10.7	7.5
Weston @ South	Weston E/B	14000	7.3%	1000		
	Weston W/B	17000		1240		
	South	10000		720	11.7	8.2

Figure 10 (continued). Reproduction of summary tabulation, hot spot verification analysis, Waltham

VERIFICATION OF HOT SPOT POTENTIAL

Project: HOT SPOTS Date: OCT. 10, 1975

City: WALTHAM By: AHG

Location Classification: UNINTERRUPTED FLOW

Location: Approach	Adjusted ADT 1977	Peak Hour Traffic		Estimated CO Concentrations	
		% ADT	Volume	1-Hour	8-Hour
RTE. 128 (@ Main St.)	99000	11.0%	10900	24.3	17.0
Trapelo Road (Near B.C.L.)	15000	8.8%	1320	11.4	8.0
Weston Street (Near Rte. 128)	21000	7.3%	1540	13.5	9.5

Figure 10 (continued). Reproduction of summary tabulation, hot spot verification analysis, Waltham

SECTION VI

OBSERVATIONS AND RECOMMENDATIONS FOR FURTHER STUDY

GENERAL

During the development of the screening guidelines, a number of observations were made that warrant mention in this document. These observations focus on several different topics and the purpose of presenting them here is to indicate areas where research or study is required, and to generally "raise questions" rather than resolve issues.

REASONABLE RECEPTORS

A crucial element of the hot spot verification process is the identification of ~~a~~ reasonable receptor proximate to the site under analysis. As can be seen from Figures 3, 5, and 8, the computation of ambient carbon monoxide concentrations is highly sensitive to lane-edge to receptor distances; therefore, it follows that in order for accurate, consistent assessments of potential hot spots to be possible, some rather specific criteria must be estabished for both defining exactly what a reasonable receptor is, and identifying receptors in the field.

Similarly, there must be a firm basis on which to decide whether the National Ambient Air Quality Standard for maximum 8-hour average concentrations, or for maximum 1-hour average concentrations should be of primary concern in the evaluation of a particular location.

These issues, while important with regard to the basic analysis of the type presented in the Guidelines, are seen as being of the utmost importance during later phases of a hot spot evaluation program when plans are being formulated for dealing with specific hot spot problems. Since the implementation of most strategies for reducing ambient concentrations of carbon monoxide involve significant economic and social impacts, the need for such actions must be substantiated in definite terms, indicating specific criteria on which the need for the actions are based. These criteria should be in the form of a regulation which, as a minimum, specifically defines "reasonable receptors" and defines procedures for determining which National Ambient Air Quality Standard - the 8-hour or the 1-hour average concentration - should be considered.

DEFINITION OF CARBON MONOXIDE HOT SPOTS

Discussion in the Guideline report indicates that ambient air quality at any particular point in time and space is largely a function of the intensity of emissions of the pollutant and the prevailing meteorological conditions. The analytical techniques described in the Guideline were based on investigating variations in the parameters which impact emissions intensity, while only one particular set of meteorological conditions was assumed throughout. The procedures described then were really aimed at determining the hot spot potential of an intersection or street section since the specific meteorological characteristics of the location were not accounted for.

If a screening technique were to be developed for indicating whether or not a location was, in an absolute sense, a carbon monoxide hot spot, the procedure would necessarily involve input from either long-term monitoring at the site, or the use of a line source or area source model utilizing extensive historical micro and macro meteorological data. The absolute determination of whether a location is a carbon monoxide hot spot or not, must focus on determining both severity and frequency of violations to the National Ambient Air Quality Standards. A technique of this sort is obviously much more rigorous than the screening techniques proposed in the Guidelines for identifying hot spot potential.

The first step in the classical scientific process for problem solving is to state the problem. This concept, without question, holds true for analyzing and resolving air quality problems - the initial step should be to identify the problem completely in terms of severity and frequency of violations to the air quality standards. Given the relative level of sophistication of the screening techniques developed in the Guideline, it is obvious that a complete statement of a location's air quality problems cannot be developed from the results of screening analyses; the limitations of the screening techniques presented must be thoroughly understood.

LEVEL OF EFFORT

Inasmuch as the techniques developed in the Guidelines are admittedly not precise, the level of effort expended in analyzing a location should not be more than is necessary to develop reasonable estimates of traffic volumes, vehicle class distributions, roadway capacities, etc. It is suggested here that techniques for obtaining traffic data should focus on obtaining good estimates rather than absolute values for any data element. For example, if a number of locations within any general area are to be analyzed, the traffic volume data can be developed utilizing a combination of long-term automatic traffic recorder (ATR) counts of at least 24-hour duration, and numerous short-term, manual counts (usually of 1-hour duration). Other data, such as vehicle classification counts, can be obtained through conduct of numerous sample counts throughout the street network. Use should also be made of construction plans, reports, and other records for determining elements such as signal timing and phasing, and physical characteristics of a location.

APPENDIX A

SELECTION OF MODELS FOR DETAILED ANALYSIS

The following text is intended as a preliminary modeling guideline, to supplement the accompanying volume of screening guidelines. It is recommended that this material be the basis for additional development of guidelines for the planning aspects of hot spot control.

INTRODUCTION

This is a draft guideline on how to prepare for and perform detailed modeling of those locations that are to be studied further for their hot spot potential. It is intended that modeling be performed after the screening process (described in the guideline volume) has been completed. Normally it would be necessary to model only those locations that are shown by the screening process to be potential hot spots.*

Modeling can serve two purposes:

1. Modeling can provide an independent, quantitative verification of the screening process. This is advantageous for determining the effect of those local conditions (such as terrain or meteorology) that are not considered in the screening process.
2. Modeling provides a consistent technique for evaluating alternative control measures. This is particularly advantageous where multiple locations are affected and thus where manual calculations, using the screening guidelines, would be inefficient or time-consuming.

There may be instances when the planner decides that the second-stage screening (verification) is sufficiently detailed and that modeling is not required. So long as alternative improvements are evaluated on the same basis, such an approach may well be sufficient. This portion of the guidelines should still be consulted in such an event, however, because it discusses the needs and costs for data collection which may be required for verification screening as well as for modeling.

The models chosen for discussion in this Appendix are those which are especially suited to analysis of CO hot spots. There are many additional models available for handling the usually free-flow, uncongested flows occurring on major throughways, and for these types of applications the reader is referred to the following two reports:

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*Modeling might be done without screening in those cases where CO standard violations are known to exist, such as where air quality monitoring has been performed, or where CO standard violations are widespread such as in a Central Business District.

- A Critical Review of Mathematical Diffusion Modeling Techniques for Predicting Air Quality with Relation to Motor Vehicle Transportation. Washington State Highway Department Research Program Report 12.1. June 1973.
- Computer Modeling of Transportation-Generated Air Pollution: A State-of-the-Art Survey. U.S. DOT Report No. DOT-TSC-OST-72-20. June 1972.

Table A-1 presents a synopsis of the models and the features of each to be discussed in more detail in the remainder of this Appendix.

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Table A-1. OVERVIEW OF HOT SPOT MODELS

Hot spot model	Applicability	Data requirements	Output	Strengths/weaknesses
APRAC-1A	Mesoscale analyses. Identification of hot spot tendencies. Street canyon concentrations.	Surface and upper air meteorological data. ADT on each traffic link, hourly distributions of ADT. Gasoline sales data.	One-hour CO concentrations in each of up to 625 grid elements. Frequency of occurrence of different CO concentrations. Hourly CO values at up to 10 locations. Street canyon concentrations.	Multi-purpose model capable of handling an urban region. Background CO level calculation. Requires use of computer. Relatively extensive data and manpower requirements. Not especially directed towards hot spot analysis.
Modified APRAC[a]	Mesoscale and project analyses. Identification of hot spot tendencies. Street canyon concentrations.	Link output data from FHWA Urban Planning System 360. Wind data from up to 100 stations optional.	Similar to APRAC-1A	Can use traffic link data directly from System 360 output. Includes line source diffusion model. Allows curved wind field. Emissions calculation based on AP-42, Supplement 5. Better suited for hot spot analysis than APRAC-1A. Requires computer. Extensive data and manpower requirements.
Indirect Source Review Guidelines	Well suited to hot spot evaluation. Microscale analysis.	Minimal data needs. Demand volumes and capacities of roadways being analyzed. Use of emission correction factors recommended. Two week's CO data for "adjusting" concentration estimates recommended.	Concentrations near roadway under "worst case" conditions.	Simple technique, well supported by documentation. Relatively low data and manpower requirements, does not require computer. Numerous assumptions may not be universally applicable.
GCA Intersection Model	Microscale analysis of intersection related hot spots.	Same as above plus modal emissions data, signal data.	Concentrations near roadway under a variety of user-specified conditions.	More flexible than above, fewer assumptions, otherwise similar. Background must be included separately.
ISMAP	Microscale hot spot analyses. Selection from among numerous traffic engineering alternatives.	Traffic engineering parameters of roadways and signals, traffic volumes. Wind speed and direction.[b]	Traffic flow and emissions data. Hourly CO concentrations at each of up to 200 receptors.	Treats parallel wind case, elevated links. Concentrations calculated for up to 200 receptor locations. Includes traffic assignment/flow model. Requires the use of a computer and relatively extensive data and manpower. Not fully validated.
TFAP	Microscale hot spot analyses. Selection from among numerous traffic engineering alternatives.	Traffic engineering parameters of roadways and signals, traffic volumes. Wind speed and direction.	Traffic flow and emissions data. Hourly CO concentrations at user-selected locations.	Microscale, individual vehicle traffic flow model. Deterministic treatment of selected traffic parameters. Requires the use of a computer and relatively extensive data and manpower. Extensive treatment of single roadway with multiple intersections. Not fully validated.

[a] Not operational at the publication of this report.

[b] This model was developed specifically for indirect source analysis and hence requires some additional input data not required for more general hot spot analyses. These input requirements may be nullified in operation.

DETERMINATION OF HOT SPOTS

Introduction and Summary

The following discussion presents the analytical techniques which are available for determining hot spots once a hot spot potential has been identified by the screening procedure. More specifically, the analytical techniques or models presented include:

- APRAC-1A
- Modified APRAC
- Indirect Source Review Guidelines
- The GCA Intersection Model
- ISMAP
- TFAP.

For each of these techniques information is given on data needs, data collection, application, and cost. Detailed guidance is not provided on collection of traffic data, inasmuch as this guideline is intended primarily for planners and engineers with traffic expertise.

In many cases this discussion cannot be exhaustive, as in the cases of the APRAC-1A and Indirect Source Review Guidelines for which extensive documentation exists. Rather this discussion is intended to provide guidance on alternative methods which may be employed and the conditions for which they are appropriate. However, in those instances in which it is desirable to go into more detail, especially as regards application, that detail will be presented.

APRAC-1A

The APRAC-1A urban diffusion model[1] was developed to simulate CO concentrations from readily available meteorological and traffic data. The computer program can be used to make calculations of the following types:

- Grid-point model: concentrations at various locations in a geographical grid, providing detailed horizontal concentration patterns for operational or planning purposes.
- Synoptic model: hourly concentrations as a function of time, for comparison and verification with observed concentrations and for operational applications.
- Climatological model: the frequency distribution of concentrations, for statistical prediction of the frequency of occurrence of specified high concentrations in connection with planning activities.

All three modeling options of APRAC-1A are useful for determining locations on the mesoscale with a tendency for high concentrations.

In the model, the concentration contribution at a particular receptor location from links other than the receptor street is calculated by means of a receptor oriented Gaussian plume model. For a given hour, the model sets up a series of area sources upwind of the receptor point. Each of these area sources is assigned an emission strength based upon the link elements contained within each. The vertical dispersion of the CO plume which occurs between the area source and receptor will depend upon a vertical dispersion parameter which is in turn a function of wind speed, cloud cover, and time of day. The dilution factor of CO along the axis of the plume is proportional to the wind speed.

It is unlikely that the model will define a hot spot when run in the preceding form, since it applies to topographically uncongested areas, and furthermore it does not treat the effects of traffic congestion on emissions.

The model may be run, however, in a form applicable to congested areas where a "street canyon" is formed by surrounding buildings. When run in this form, the Gaussian plume concentrations are then added to values obtained by use of a street canyon submodel which accounts in a more realistic way for the effect of emissions on the receptor street itself. An illustration of the physical basis for this submodel is given in Figure A-1. Winds blowing over the canyon carry background "roof top" concentrations of CO down the wall of buildings on the opposite side of the street. Emissions from traffic on the street are then picked up by the eddy and transported to the upwind side of the street and then up the side of the buildings. A circulation pattern of this type would result in the highest concentrations being observed at street level on the upwind side. In the context of the model, the only physical street canyon variables which are at the disposal of the user are the width of the street (building to building) and its heading with respect to north. The building height is fixed at 38.8 meters. If the street canyon option is utilized, four CO levels are given for a particular receptor, two near street level on opposite sides of the link, and two more concentrations at a higher elevation. The street canyon submodel option cannot be exercised when the model is run in the grid point mode.

Data Needs - Some further insight into the operation of the model can be gained from the following discussion of input data requirements and the relative importance of the associated variables.

1. Emissions Data - In the APRAC program, emissions are parameterized simply in the form of an emission factor power law.

$$E = \alpha S^{-\beta}$$

where E = emission factor (gm/mi)

α, β = constants for a particular year, model year distribution, and weighted annual travel distribution

S = average traffic speed (mi/hr).

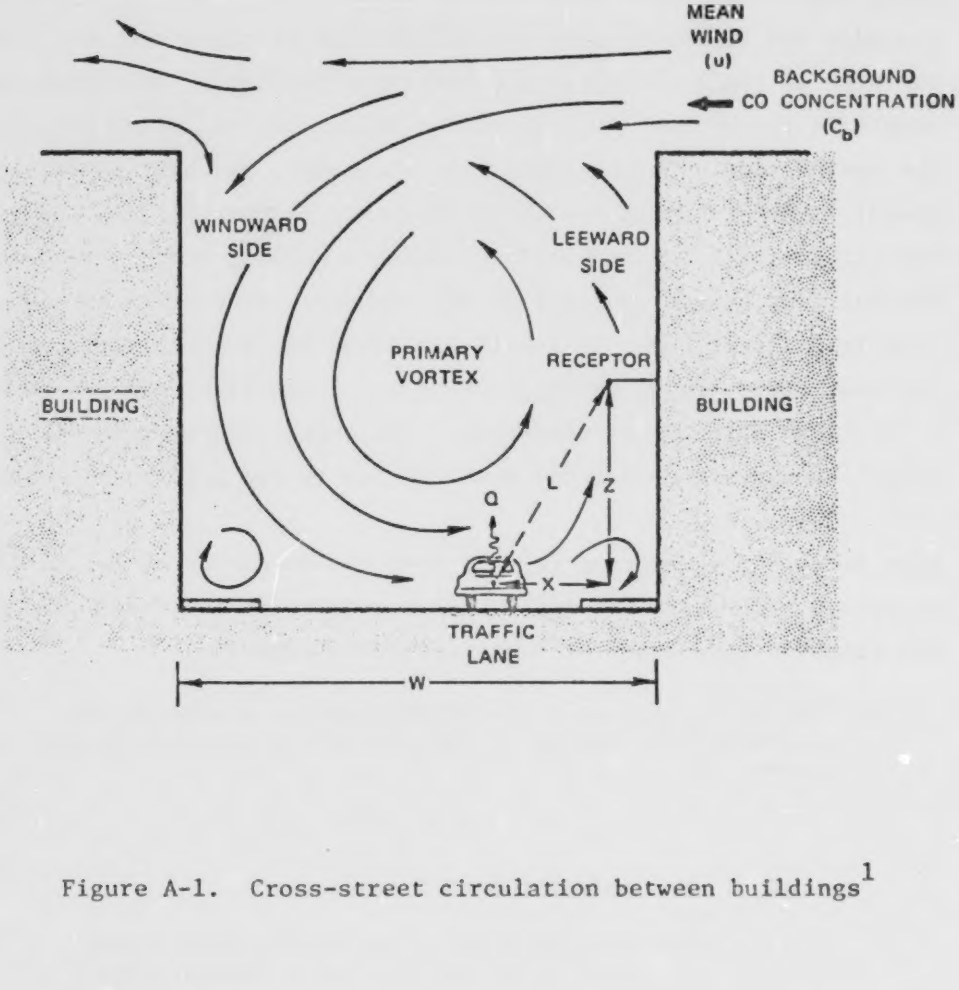
MEAN
WIND
(u)
BACKGROUND
CO CONCENTRATION
(C_b)
WINDWARD
SIDE
LEEWARD
SIDE
PRIMARY
VORTEX
RECEPTOR
BUILDING
BUILDING
Q
L
Z
X
TRAFFIC
LANE
W

Figure A-1. Cross-street circulation between buildings[1]

The constants α and β may be obtained indirectly from the FMVECP emission factors.[2] The speed S is available in the emission factor calculation since each link in the data set is characterized by one of eight speed classes.

2. Meteorological Data - The meteorological data required to run APRAC-1A are surface observations and atmospheric soundings as described below.

   a. Surface observations - Hourly measurements of wind speed, wind direction, temperature, and cloud cover are utilized in the calculation of CO transport and dispersion. Wind speed, cloud cover and time of day are used in the calculation of the vertical dispersion coefficient used in the gaussian plume submodel. The street canyon submodel requires only wind speed and direction since the dilution volume will depend upon the building configuration at any given receptor location.

   b. Atmospheric soundings - Temperature variation with height is used along with maximum and minimum daily surface temperatures to determine an hourly mixing depth, which sets an upper limit to the vertical migration of the pollutant. This mixing height parameter is usually only important in the calculation of CO concentrations due to emissions from distant sources and obviously plays no role in the street canyon calculation.

   Both surface observations and atmospheric soundings may be obtained from the National Climatic Center, Asheville, North Carolina, for weather stations closest to the location of interest.

3. Traffic Data - The basic traffic input for the APRAC model is the number of vehicles per day for an array of links whose endpoint coordinates are specified on a rectangular system in units of 0.1 miles. To account for the curvature of a particular link, the actual length of the roadway between the endpoint is input. As mentioned before, each link is also assigned an appropriate speed classification. Nonlink traffic volumes may be assigned to 4 mi^2 grid squares superimposed upon the traffic network.

   The daily traffic flow volume is apportioned for each hour of the day according to hourly traffic flow distributions specific to weekdays, Saturdays, and Sundays.

There is also the option in the program of selecting a given hour of the day as a peak hour, thereby reducing the average speed on all links by 15 percent.

4. CO Data - CO data are needed to calibrate the APRAC-1A model prior to using it to identify locations having a tendency towards hot spot development. These data should be from a time period long enough to cover a range of meteorological conditions, especially those promoting high CO concentrations.

Data Collection - Each type of data will be separately addressed.

1. Emissions Data - As mentioned previously, emissions estimates are computed by the model from individual link as well as total ADT. In addition, gasoline consumption data are used to compute background CO levels. Hence, there is no need to perform an emissions inventory for CO.

2. Meteorological Data - As described earlier, both surface observations and atmospheric soundings may be obtained from the National Climatic Center, Asheville, North Carolina.

3. Traffic Data - It is necessary to provide Average Daily Traffic (ADT) for each link (street segment) to be modeled, as well as data on the hourly distribution of volumes separately for weekdays, Saturdays, and Sundays. One volume distribution is used for all modeled links. Travel speeds are required for each link, in the form of overall average speed (including delays).

4. CO Data - CO data for use in calibrating APRAC-1A may be obtained from local or state air pollution control agencies. Alternatively, these data may be obtained from the regional office of EPA, or from the EPA in Durham, N.C., from the SAROAD system. It is best, however, to work from the local level up in obtaining data, since the data eventually find their way into the SAROAD system along this same route.

Application of APRAC - The APRAC-1A model is available on the EPA UNAMAP system, written in FORTRAN for the UNIVAC computer. If obtained in this manner, it must be modified to run on other systems. Documentation on running the model is contained in the User's Manual for the APRAC-1A Urban Diffusion Model Computer Program,[1] available through NTIS, publication PB-213-091. This manual also contains program listings for use on CDC and IBM systems.

Cost - Cost elements are as follows.

1. Emissions Data - As mentioned earlier, emissions data are computed by the program using traffic data. Hence the cost of emissions data is implicit in the traffic data assembly costs.

2. CO Data - The costs of collecting CO data will vary depending on the form in which they are received, ranging from strip charts to the computer printout format of SAROAD. On the average, approximately one man-week of effort should be sufficient for gathering the requisite CO data.

3. Meteorological Data - Surface and upper air data may be purchased from the National Climatic Center for approximately $150.

4. Traffic Data - ADT data should be available from routine traffic data collection. Where new counts are required, the usual practice is to use 24-hour or 48-hour counts. Such a count requires about one man-day to plan, perform, and reduce. Speed data may be available, but more likely will be incomplete. APRAC requires only one speed figure for the entire day, and has a built-in adjustment for peak hours. Thus, one should derive an estimate of the volume-weighted average speed for nonpeak periods. For adequate accuracy, about 10 runs are needed on each link. The time to accomplish this data collection is thus equal to about 10 times the amount of time to drive each link once, plus about 50 percent for turn-around, notations, and so on. Probably two men are needed. Additional time is required for data reduction, amounting to a few man-days or less for a typical CBD.

5. Model Application - The costs of applying the APRAC-1A model include the costs of preparing input data, calibration, and actual machine time, exclusive of the

data collection costs. On the average, one man-month should be sufficient to perform the input preparation and output interpretation tasks. The machine costs are variable, depending on the costs at the computer facility which is used, and the mode in which the model is run. One hour of computer time is an estimate of these costs. Table A-2 displays the run-time for the CDC-6400.[1]

Table A-2. APRAC-1A CENTRAL PROCESSOR TIME (SECONDS) ON THE SRI CDC 6400 COMPUTER[a] (FOR COMPUTING CO CONCENTRATION IN ST. LOUIS)

	Model			
	Synoptic			
Process	One receptor (NPT = 1)	More than one receptor (NPT > 1)	Climatological	Grid-point
Compilation	10.5	10.5	10.5	10.5
Preliminary computation	6.1	5.9	5.9 + 7.5 x NPT	5.9
Basic computation (per receptor per hour)	1.14×10^{-1}	2.25×10^{-1}	3.7×10^{-3}	2.85×10^{-1}

[a] This computer has an add time of 1.1 microsecond and a cycle time of 1.0 microsecond.

Modified APRAC[3]

While this model has not been developed at the time of this report, it is expected to be available within the next few months. It is included in this discussion since it offers some improvements over the APRAC-1A model in determining hot spots, and it is expected to be operational shortly. The format of this discussion departs from the itemized discussion presented for APRAC-1A, and the anticipated modifications are presented here in a more narrative fashion.

The APRAC modification affects essentially all aspects of the model including the handling of traffic data, emissions calculations, meteorological inputs, and diffusion calculations. To begin with, the modification allows an option for using link data directly from the loaded historical record in the FHWA Urban Planning System 360 program battery. These data are used in the emission calculations. In the past these data have had to be coded and input by the user. The modified version of APRAC also computes vehicle speeds from volume and capacity information and the capacity restraint relationship, where previously speed was input for each of up to eight roadway types. In addition, a 1-kilometer square grid network is used for area source emissions, including those from secondary traffic. Secondary traffic volumes are calculated (rather than input) from total and primary link VMT data. Emissions from secondary traffic are also calculated for each grid element from ratios of adjusted primary link VMT data in each grid element to the adjusted total VMT on primary links.

Perhaps the most important feature of the modification involving the handling of traffic data is that it allows traffic volumes, pollutant emissions, and pollutant concentrations to be calculated from the common base of the FHWA program battery for both present and future years.

The previous method of computing vehicle emissions as a function of speed was based on an equation of the form

$$E = \alpha S^{-\beta} ,$$

where the quantities α and β were developed by Stanford Research Institute. This is replaced by the technique given in the latest revision to AP-42, Appendix D.[3] New items in the AP-42 revision include a new method for calculating speed correction factors, temperature correction factors, hot and cold start correction, and a correction for inspection/maintenance programs. The new method of AP-42 is summarized for light-duty vehicles (automobiles and light trucks) by the relation:

$$e_{npstwx} = \sum_{i=n-12}^{n} c_{ipn}\, m_{in}\, v_{ips}\, z_{ipt}\, r_{iptwx}$$

where e_{npstwx} = Composite emission factor in grams per kilometer (g/mi) for calendar year n, pollutant p, average speed s, ambient temperature t, percent cold operation w, and percent hot start operation x.

c_{ipn} = The FTP (1975 Federal Test Procedure) mean emission factor for the i^{th} model year light-duty vehicles during calendar year n and for pollutant p.

m_{in} = The fraction of annual travel by the i^{th} model year light-duty vehicles during calendar year n.

v_{ips} = The speed correction factor for the i^{th} model year light-duty vehicles for pollutant p, and average speed s. This variable applies to CO, HC, and NO_x only.

z_{ipt} = The temperature correction for the i^{th} model year light-duty vehicles for pollutant p and ambient temperature t.

r_{iptwx} = The hot/cold vehicle operation correction factor for the i^{th} model year light-duty vehicles for pollutant p, ambient temperature t, percent cold operation w and percent hot start operation x.

Composite crankcase emissions can be determined using:

$$f_n = \sum_{i=n-12}^{n} h_i\, m_i$$

where f_n = The composite crankcase hydrocarbon emission factor for calendar year n.

h_i = The crankcase emission factor for the i^{th} model year.

m_i = The fraction of annual travel by the i^{th} model year during calendar year n.

The composite evaporative hydrocarbon emission factor is given by:

$$e_n = \sum_{i=n-12}^{n} (g_i + k_i d) m_i$$

where e_n = The composite evaporative hydrocarbon emission factor for calendar year n in grams/day (lb/day).

g_i = The diurnal evaporative hydrocarbon emission factor for model year i in grams/day (lb/day).

k_i = The hot soak evaporative emission factor in grams/trip (lb/trip) for the i^{th} model year.

d = The number of daily trips per vehicle.

m_i = Was defined previously.

Other, similar types of relationships are given for light-duty diesel vehicles, heavy-duty gasoline and diesel vehicles, and motorcycles.

The most striking modification involving meteorological data inputs and handling is the allowance for input of up to 100 wind vectors for the region being modeled. Previously only one (different) wind vector was used for each hour of the day. Although curvature in wind flow fields is not exactly handled by the modification, it will serve to describe pollutant transport much better than before. Mixing height by hour is also allowed as an input under the modification.

The final area of APRAC modification applies to line source diffusion. In its original form (APRAC-1A) the only treatment of line source diffusion is the street canyon submodel, so that the impact of a particular roadway link on a receptor could only be computed by assuming a street canyon, whether the particular roadway was in a street canyon or not. The modified APRAC is to contain a line source model from the Indirect Source Model for Air Pollution (ISMAP) which is Gaussian and does not assume a street canyon.

The line source model of ISMAP is similar to the EPA HIWAY model in that it computes the contribution at a receptor of a number of point sources located along the roadway some distance ΔL apart, where ΔL is a function of the error involved in the discrete point source assumption. In ISMAP the maximum tolerable error is chosen as 5 percent. In practice, ΔL is solved analytically assuming the most sensitive case of a wind perpendicular to the roadway. This value is then halved and the resulting spacing is used in the diffusion calculations. In HIWAY, a value of ΔL is chosen which is successively halved until concentration estimates converge to within 2 percent or less.

Concentrations at the receptor due to each point source are computed and summed. The concentration calculations are performed using the Gaussian relation

$$\chi_p = \frac{Q_p}{\pi\sigma_y(d_w)\sigma_z(d_w)u} \exp\left\{-1/2 \frac{d_c^2}{\sigma_y^2(d_w)}\right\} \exp\left\{-1/2 \frac{H^2}{\sigma_z^2(d_w)}\right\}$$

and

$$\sigma_y(d_w) = a|d_w|^b + c$$

$$\sigma_z(d_w) = f|d_w|^g + h$$

where χ_p is the CO concentration, gm m^{-3}.

u is the wind speed, m sec^{-1}.

Q_p is the point-source emission rate, gm sec^{-1}.

$\sigma_y(d_w)$ is the lateral standard deviation of plume concentration, m.

$\sigma_z(d_w)$ is the vertical standard deviation of plume concentration, m.

H is the emission height, m.

d_c is the crosswind distance from point source to receptor, m.

d_w is the distance along wind direction from point source to receptor, m.

a,b,f,g are the diffusion coefficients and exponents.

c,h are the constants representing initial diffusion, m.

As is evident, receptor height is not included and is hence assumed equal to zero. Receptor heights other than zero can be accommodated, however, in the present formulation by assuming an emission height of zero (suggested in ISMAP manual) and letting H equal the receptor height.

Indirect Source Review Guidelines

The indirect source review guidelines, Volume 9 of EPA's Guidelines for Air Quality Maintenance Planning and Analysis,[4] provide the first technique presented here which attempts to incorporate the effects of local traffic flow and emission characteristics into the hot spot determination process. While certain generalized assumptions are implicit in the technical approach of these guidelines, they are nevertheless an improvement over previously described procedures in making a local hot spot determination. (The EPA Indirect Source Guidelines are the foundation for the screening procedures.)

Data Needs - Several types of data are needed.

1. Emissions Data - Emissions data are "built in" to the guidelines and need not be developed. There are, however, allowances for cold starts, altitude, the FMVECP, and local factors which affect the concentration estimates provided by the guidelines, and which should be taken into account.

2. CO Data - The guidelines recommend that CO data be collected for 14 days for at least one site near the expected hot spot to be used in adjusting the concentrations predicted by the modeling approach.

3. Meteorological Data - Meteorological data are not required, since the approach assumes worst case conditions.
4. Traffic Data - The traffic data requirements are demand volumes and capacities for roadways being analyzed.

Data Collection - Each type of data will be described.

1. Emission Data - As mentioned previously, there is no need for emission data collection.
2. CO Data - CO data may be collected by continuous monitoring near the suspected hot spot.
3. Meteorological Data - These data need not be collected.
4. Traffic Data - Data collection is discussed in Sections I and II and consist of present volumes (ADT) and physical data to determine capacity.

Application of the Indirect Source Review Guidelines - Ample information, including examples, is presented in the previously mentioned EPA publication.[4] The method is relatively straightforward, does not generally require a computer, and is usually applied as a quantitative screening procedure which yields actual concentration estimates. (See also Section II of this volume for discussion of the version of the Indirect Source Guidelines used there as a CO screening tool.)

Cost - Table A-3 presents anticipated costs of data collection and application as given in the EPA guidelines report.

Table A-3. COST TO OBTAIN DATA FOR INDIRECT SOURCE REVIEW

Effort	Approximate cost
1. Obtaining traffic data not already available, filling out the application form and applying the screening procedure described in Section 4.0 without air quality monitoring data.	$3000.
2. Obtaining and reducing 14 days of air quality monitoring data collected at one site.	$6000.
3. Performing a complete modeling analysis including the costs of monitoring meteorological, air quality and traffic data at several locations, and computer costs required to use observed data in an atmospheric dispersion model.	$35,000-$50,000.

The GCA Intersection Model

This model, or approach, was developed in support of the EPA's indirect source review guidelines, and the guidelines are an adaptation of it with many simplifying assumptions.

Data Needs - As before, each type is listed separately.

1. Emission Data - Part of the key to this approach is the use of emission data which depend on driving mode as well as speed to characterize emissions and concentrations at congested locations.

   These data may be developed by the EPA "Automobile Exhaust Emission Modal Analysis Model"[5] and the use of appropriate emission factors. Details on how this may be accomplished are presented elsewhere in detail and are not within the scope of this review of techniques.

2. CO Data - As with the indirect source guidelines, it is recommended that CO data be collected for 14 days for at least one site near the expected hot spot to be used in adjusting the concentrations predicted by the modeling approach.

3. Meteorological Data - Meteorological data may be collected for use in calibrating the predictive model in conjunction with the CO data, although worst case conditions may be assumed in estimating the magnitude of a particular hot spot.

4. Traffic Data - The traffic data required are those needed to estimate emissions. These are

   - Cruise speeds
   - Acceleration and deceleration values
   - Demand volumes
   - Capacities
   - Signal data.

Data Collection - By type, data collection is as follows:

1. Emissions Data - As mentioned previously, emissions data are computed by the "Modal Model" based on vehicle operating characteristics on the roadway.

2. CO Data - CO data may be collected by continuous monitoring near the suspected hot spot.

3. Meteorological Data - If these data are desired they may be obtained from the National Climatic Center, Asheville, N.C.

4. Traffic Data - Rather substantial traffic data collection is needed for this model. Cruise speeds, acceleration and deceleration data, and delay times can be collected by a "moving car" technique in which a vehicle with driver and observer is driven so as to match the average characteristics of traffic. In the development of the GCA intersection model, two such vehicles were operated continuously through the one intersection, while automatic traffic counters were in operation.[6] For practical applications, it is recommended that the data be disaggregated as follows:

   - By travel lane at each intersection (including separate ATR counts by lane).
   - By hour of the day, with about 10 speed-delay runs for each lane of each approach of each intersection, for each hour (runs can be on several days). Thus it will probably require on the order

of 5 to 10 man-days per intersection to collect and reduce this data. In addition, physical data must be collected to allow calculation of capacities.

Application of the GCA Intersection Model - The details of applying the modeling technique are provided elsewhere in detail.[6-9] They may be summarized as

- Identify the parameters necessary for calculating the expected mean total queue length. These parameters are:

  (1) V = hourly demand volume

  (2) Cycle length

  (3) G/C = required G/C ratio

  (4) G'/C' = actual G/C ratio provided or if the signal is fixed time

  (5) G/C = actual G/C ratio provided

  (6) Capacity per hour of green

- Compute the expected mean total queue length using Equation (A-1) for a demand actuated traffic signal or Equation (A-2) for a fixed time signal:

$$\overline{N}' = \frac{(V\ \text{veh/hr})\ (1-G'/C')\ (\text{cycle length})}{(3600\ \text{s/hr})\ (1-G/C)} \tag{A-1}$$

$$\overline{N}' = \frac{(V\ \text{veh/hr})\ (1-G/C)\ (\text{cycle length})}{(3600\ \text{s/hr})\left(1 - \dfrac{V\ \text{veh/hr}}{C\ \text{veh/hr of green}}\right)} \tag{A-2}$$

- From the queue length, speed, acceleration, and deceleration data, use the Modal Model to compute emissions.

- Calculate the emission strength (gm/m-s) over the distance occupied by the queue by adding:

$$\frac{\text{(mean stopping and starting emissions gm/8 m)}}{\text{(8 m) (cycle length s)}} +$$

$$\frac{\text{(cruise emissions gm/8 m) (V veh/hr) (cycle length s)}}{\text{(8 m) (3600 s/hr)}} +$$

$$\frac{\text{(idle emission rate gm/s) (1/2 the length of the red phase s)}}{\text{(8 m)}}$$

= emission strength over the queue length (gm/m-s).

- Assume that only the cruise speed emission strength exists upstream and downstream of the queue (excluding the center of the intersection).
- After the emission strengths are found over the queue lengths for all approaches, average them and assume this emission strength for lanes in the center of the intersection.
- Apply a diffusion model, such as the EPA HIWAY model, or a dilution model, such as the APRAC-1A street canyon model, as the topography dictates.

Cost - The initial cost to apply this method can be placed at six man-months although this is a function of whether or not a computer is used for diffusion modeling. Once this initial application has been made, subsequent applications may be made for approximately three man-months of effort or less.

ISMAP

This model, the Indirect Source Model for Air Pollution,[10] is in essence a computerized version of the GCA Intersection Model with some modifications. Both this model and the TFAP model discussed subsequently have not received the same degree of use as previous models. They may be considered in the developmental stage *of application*, since the ramifications of their application have not yet been discovered by widespread use. Hence, they will be discussed in general terms.

As previously mentioned, ISMAP is essentially a computerized version of the GCA model, capable of handling a number of intersections and links at one time.

In the traffic analysis, facility traffic is assigned to alternative routes and added to through traffic counts. Travel patterns are determined on the basis of trip demand, intersection capacities, and phase lengths for actuated signals. The traffic flow analysis is rerun for consecutive hourly periods; accumulations of vehicles in parking lots and queues on streets are retained as initial values for subsequent periods. An intersection subroutine calculates delays at each intersection and street of the network; the outputs are average vehicle delay and queue length for each approach and turning movement.

The traffic flow analysis submodel provides the following inputs to the modal emissions submodel for each link and zone: (1) vehicle-miles of steady-speed driving, (2) speed during steady-speed operation, (3) number of stops and starts, and (4) time spent stopped and idling. Emissions are then calculated for each mode (i.e., cruise, idle, and acceleration/deceleration) and are assigned accordingly to varying segments of each link.

The dispersion submodel is based on the use of the Gaussian point-source formulation to treat line-source emissions from roadways and area source emissions from parking zones. In this way, both variable emission rates along links and winds parallel to roadways may be accommodated. Elevated links can also be treated. Up to 200 receptor locations can be specified for a single hourly run.

While the preceding analytical techniques have been validated, a validation has not yet been performed for ISMAP.

TFAP

This model, the Traffic Flow and Air Pollution Model, was also developed by GCA. This model includes a traffic flow submodel which computes detailed information on individual vehicle motions (acceleration, deceleration, cruise, and idle) through a string of signalized intersections, each with its own characteristic input parameters including signal phase times, offset, approach speed, departure speed, and turning fractions. The computed vehicle motions are then combined with an emission submodel which calculates emissions based on driving speed and mode for all vehicle motions. The emissions from each vehicle are added at all points along the roadway to calculate spatially (and temporally) detailed emission profiles. In this model, queue lengths, total delay, and idle are computed deterministically rather than by the probabalistic approach of previously described models.

The results of the traffic flow and emissions submodels are then input to a diffusion submodel — either a Gaussian line source model or a street canyon dilution model — to compute concentrations. A small-scale validation of this model has been completed.[11]

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APPENDIX B

EVALUATION OF SELECTED TRAFFIC ENGINEERING MEASURES AND THEIR EFFECT

The following text is intended as a preliminary planning guideline, to supplement the accompanying volume of screening guidelines. It is recommended that this material be the basis for additional development of guidelines for the planning aspects of hot spot control.

GENERAL

This is intended as a guideline for the selection of control measures for carbon monoxide hot spots. Inasmuch as these guidelines are directed towards individual hot spots, this discussion excludes control measures that would be applied to entire states or large substate regions, such as the Federal new car pollution controls, retrofit of pollution controls on existing cars, and inspection and maintenance of existing vehicles. Information on such areawide control measures that may be applicable to your community is available from your state air pollution control agency. Furthermore, tail pipe controls such as inspection/maintenance and new car pollution controls are explicitly considered in the screening guidelines.

The control measures to be described here are primarily traffic engineering techniques, so the planning and selection of a control program should be undertaken with the assistance of traffic engineering professionals. Nonetheless, the discussion presented here will be useful to city planners and other municipal officials who need an overall understanding of what can be done about CO hot spots and of what is required to achieve various degrees of improvement.

Municipalities that do not have staff traffic engineers are advised to obtain the assistance of their county or state highway or traffic agencies, or of private consulting firms, when implementing a program to control CO hot spots. Experience in both traffic engineering and air pollution control is essential to successfully controlling CO hot spots.

The remaining discussion in this section is divided into two parts. First various control measures will be described, including their effects on traffic and on CO. Next, the social, economic, institutional, legal, and other aspects of implementation are presented. Examples and bibliographic references are provided throughout.

TRAFFIC ENGINEERING MEASURES AND THEIR EFFECTS

Introduction

The influence of traffic activity in the vicinity of those locations known to be experiencing excessive concentrations of CO ("hot spots") is directly related to the volume of traffic and inversely related to the vehicle operating speeds on adjacent street and highway facilities. Consequently, efforts to reduce local CO emissions and concentrations are geared toward (1) improving the flow of traffic in the vicinity of hot spots through facility design and traffic control changes, or (2) redistributing traffic to reduce the amount of travel in the vicinity of hot spots, or both.

Many CO hot spots can be improved by simply applying good traffic engineering practice. The "control measures" are often the same techniques that would be used to improve traffic flow, because emissions are reduced by any action that reduces delays, smoothes flow, reduces stop and go driving, and diverts traffic away from congestion points. This is important to keep in mind, particularly because it will aid the public's acceptance of control measures when they are viewed in this light.

Two general types of control measures are to be discussed: traffic flow improvements and traffic redistribution measures.

Traffic flow improvement strategies considered in this section have been previously identified and analyzed in the literature[1,2,3,4] and have been categorized[4] into the following types:

- Modification of existing street use, including individual one-way streets.
- Increase in effective facility size.
- Pedestrian controls.
- Traffic control signals.

These measures are primarily designed to increase average vehicle operating speeds by reducing delays, idling periods and stops and starts near specific hot spots.

In the event that these microscale[*] improvements aimed at smoothing traffic flow or increasing vehicle speed will not reduce emissions sufficiently to meet the National Ambient Air Quality Standards (NAAQS), it may be necessary to implement measures to redistribute traffic away from hot spots. Traffic redistribution measures often affect a wider geographical area than do traffic flow improvement measures and include:

- Vehicle - free zones
- Vehicle restriction zones
- One-way street systems

These measures attempt to redirect traffic away from hot spots in such a way that no new hot spots develop elsewhere.

Examples of Traffic Flow Improvements

These materials will describe some examples of measures to improve traffic flow and their quantitative effects on vehicle operating characteristics and on CO concentrations. Many of the examples discussed are based on experiments conducted in Louisville, Kentucky and Newark, N.J.[3] in 1968 as part of the National Cooperative Highway Research Program. These measures are microscale in scope in that their measured effect is limited to specific intersections or road segments. Much of the following discussion is taken from a publication[4] of the U.S. Environmental Protection Agency, APTD-1364, which, in turn, is based on the NCHRP research results.[3]

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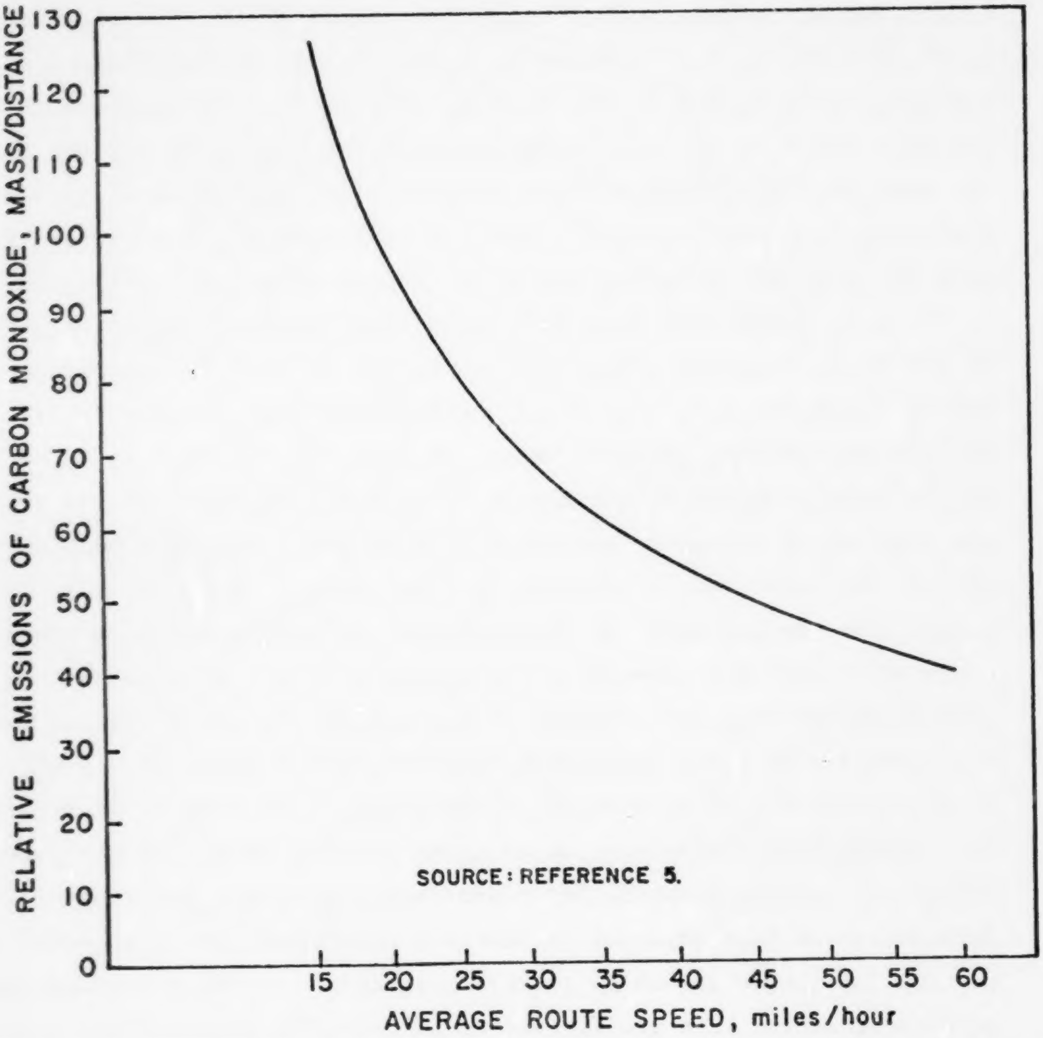
[*] "Microscale" means highly localized. In this context, microscale measures are identified on the basis of individual intersections, whereas macroscale measures relate to larger areas, such as entire business districts.

Several general remarks are in order before presenting the results of the research. First, for a given traffic volume, CO emissions are inversely related to the average vehicle travel speed and proportional to the average vehicle delay time. (See Figure B-1). The significance of an increase in vehicle speed as it affects CO concentrations depends not only on the degree of the increase in vehicle speed but also on the baseline speeds prior to implementation of the measure to improve flow. For example, increasing vehicle speeds from 15 to 20 mph will reduce CO emissions by a greater amount then will an increase in vehicle speeds from 20 to 25 mph (assuming all other factors remain constant). In contrast, a 10 second reduction in vehicle delay time is just as significant at the 20 to 30 second range as it is at the 90 to 100 second range. Baseline vehicle speeds and delay times depend upon existing traffic volumes and facility capacity which, in turn, is dependent upon the physical characteristics of the street network and the current type of traffic engineering measures influencing the original operating conditions. Second, the experimental results presented here occurred in the short term. Longer time periods would be required for the traffic flows to reach a state of equilibrium throughout the street network. For example, improved traffic flow can have the long range effects of generating more trips and longer trips which will increase vehicle miles of travel, which is counterproductive to reducing CO emissions. The long range impact of the traffic flow improvement on CO emissions will depend on the combined effects of increased speed, decreased delay, and increased travel. The implication is that physical or economic restraints may be required to control the future growth of travel in an area. Third, the experimental results presented here are limited to the specific facility being improved. In reality the impact of a traffic flow improvement will extend beyond a specific facility to adjacent facilities throughout the street network. For example, modification of two-way streets to one-way streets can increase the vehicle speeds and reduce the corresponding CO emissions on the modified streets but may increase the traffic volumes in the vicinity of a potential hot spot as motorists are required to reroute their paths to satisfy their travel demand. The degree to which seemingly microscale



SOURCE: REFERENCE 5.

NOTE: THIS GRAPH IS FOR ILLUSTRATION ONLY AND SHOULD NOT BE USED DIRECTLY FOR COMPUTATIONS.

Figure B -1. Effect of travel speed on CO emissions improvements will have systemwide (macroscale) repercussions depends on the magnitude of the required diversion, the physical characteristics of the street network, and the existing distribution of traffic throughout the network.

For simplicity, the following presentation of the results of the NCHRP traffic flow improvement experiments is limited to changes in the average vehicle travel speed. However, in specific instances where the impact of traffic flow changes on CO emissions is quantified, both travel speed and idle delay time are considered. These examples are offered as a range of potential changes in CO emissions resulting from various measures to improve traffic flow.

Modification of Existing Street Use — The effective capacity, and hence the vehicle speeds on a given street, can be increased by modifying or restricting the manner in which that street is used. A wide range of techniques can be implemented to smooth the flow of traffic on existing streets by modifying their use. These techniques may include:

- One-way streets to eliminate (1) conflicts between left turn and through vehicles at intersections (2) friction experienced by opposing traffic and (3) improve the efficiency of signal progression. One-way streets may also reduce the total traffic volume passing a particular location.
- Reversible lanes and streets whose direction of flow can vary to accommodate shifting directional traffic demand throughout the day.
- Turning movement controls whose primary purpose is to prevent delays behind turning vehicles and thereby smooth traffic flow. Controls may range from prohibiting turns to providing special turning lanes.
- Provision of advisory information to drivers so they may anticipate pending movements and obstacles and react with a minimum of confusion and friction. This guidance is usually transmitted by signs and pavement markings.
- Physical guidance of vehicles through intersections by channelizing traffic lanes to assure smooth merging and diverging traffic flows.

The experiments conducted in Newark and in Louisville provide some before and after data to measure the impact of traffic flow improvements on vehicle speed on those streets immediately affected by the improvement.

Table B -1 summarizes the statistically significant results (at 90 percent confidence limits) of several experiments designed to investigate the impact of street use modifications on vehicle speed. In most cases it was shown that street use modifications can lead to travel speed improvements. The most successful experiments involved one-way street and directional control and lane use modifications where speeds were increased an average of 37 and 25 percent respectively.*

Although in several experiments speed reductions were recorded in minor directional flow, these losses were more than offset by substantial gains in dominant traffic streams. For example, experiment B78 in Newark involving reversible lanes showed that traffic flowing in the dominant (southbound) direction enjoyed a 56 percent increase in vehicle speed while northbound traffic endured an 8 percent reduction in vehicle speed. It is not unusual that traffic flow improvements at one point in a street network will result in deterioration of traffic flow at some other point in the network. It is important, however, to consider the tradeoffs with regard to the volume of traffic affected at each point, the magnitude and direction of the change in traffic operating characteristics and the maximum tolerable deterioration of traffic flow within the NAAQS.

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*Note that the calculated speed increases refer only to the average vehicle operating speeds while moving and do not include vehicle delays (idling periods). In many urban situations it is likely that most traffic flow improvement measures would alter vehicle delay time as well as vehicle operating speed. Idling is one of the most heavily polluting modes of vehicle operation and changes in idling time can have a significant additional impact on CO emissions.

Table B-1. SPEED CHANGES FROM STREET USE MODIFICATION EXPERIMENTS IN LOUISVILLE, KENTUCKY AND IN NEWARK, NEW JERSEY[a]

Experiment type and number	Direction	Time	Travel speed, mph[b]		Speed reduction, percent	Table and page no. ref. 3
			Before	After		
One-Way Streets:						
E 30 - Louisville Mellwood Ave.	EB	AM	16.6	20.2	21.7	Table G-1, p. 156
	EB	PM	17.3	20.6	19.1	
	EB	All	16.9	20.4	20.7	
	WB	AM	17.9	27.3	52.6	
	WB	PM	17.7	26.9	52.0	
	WB	All	17.8	27.1	52.0	
	EB	AM	20.9	20.2	- 3.4	
Story Ave.	EB	PM	18.1	20.6	13.8	
	EB	All	19.5	20.4	4.6	
	WB	AM	18.2	27.3	50.0	
	WB	PM	21.2	26.9	26.9	
	WB	All	19.7	27.1	37.6	
All directions and streets	All	AM	17.2	23.8	38.4	
	All	PM	17.5	23.8	36.0	
	All	All	17.4	23.8	36.8	
Directional control and lane use:						
E 31 - Louisville	NB	AM	10.9	19.4	78.0	Table G-3. p. 161
	NB	PM	10.7	17.9	67.3	
	SB	AM	16.6	16.6	—	
	SB	PM	15.3	16.8	9.8	
	All	All	13.8	17.2	24.6	Table G-11, p. 162
Reversible lanes[c]						
B 78 - Newark Broad St.	NB	AM	12	11	- 8.3	Tables G-9 and G-10 p. 175
	SB	AM	8	12.5	56.0	
Lane markings						
B 86 - Newark Central Ave.	EB	AM	13.7	15.7	14.6	Table G-14 p. 182
	EB	Midday	12.4	14.6	17.8	
	EB	PM	13.5	12.8	- 5.2	
	WB	AM	17.6	18.8	6.8	
	WB	Midday	13.5	16.3	20.8	
	WB	PM	14.0	13.8	- 0.4	
Channelization[c]						
A 33 - Newark Washington St.	NB	AM	9.5	11.5	21.1	Table G-44, p. 238
D 68 - Louisville		AM	23.5	24.0	0.2	Table G-74 p. 263
		Midday	25.5	25.0	- 0.2	
		PM	25.0	25.0	—	

[a] Source: Reference 4.

[b] Point-to-point speed, exclusive of delays.

[c] Before and after travel speeds were estimated from the delay ratio travel speed curve shown in Figure 45, page 57 of reference 3.

Increases in Effective Facility Size — The effective size of a facility and hence the effective capacity and corresponding vehicle speeds can be increased by making maximum use of the full curb-to-curb distance for moving traffic. For intersections in particular, the usable width of an approaching street is a prime determinant of the capacity of that approach.

The usable width of a facility can be increased by physically widening the facility where sufficient space exists or by restricting on-street parking and truck loading zones that interfere with moving traffic.

Table B-2 summarizes the results of an experiment in Newark to improve traffic flow by restricting the use of truck loading zones. The observed increase in travel speed from 4.0 to 5.5 mph is substantial and would have a significant impact on reducing CO emissions in the area.

Table B-2. SPEED CHANGES RESULTING FROM INCREASING EFFECTIVE FACILITY SIZE IN NEWARK, NEW JERSEY[a]

Experiment type and number	Direction	Time	Travel speed, mph[b]		Speed increase percent	Table and page no. ref. 3
			Before	After		
Truck loading restrictions:						
C 123 - Newark University Ave.	Between Lackawanna Ave. and Orange St.	All	4.0[c]	5.5[c]	37.5	Table G-34, p. 217

[a] Source: Reference 4.

[b] Point-to-point speed, exclusive of delays.

[c] Before and after travel speeds were estimated from the delay ratio travel speed curve shown in Figure 45, page 57 of reference 3.

Pedestrian Controls — The manner in which pedestrian movements conflict with vehicle movements can have a significant impact on local traffic flow and CO emissions. For maximum safety for the pedestrian, vehicles and pedestrians should ideally be totally separated with physical barriers such as under/overpasses, fences and walkways. However, practical and ecomonic feasibility dictates certain compromising alternatives to total separation. Crosswalks and walk/don't walk signals are commonly used alternatives to total separation that tend to slow the flow of traffic.

Table B-3 summarizes the results of an experiment in Newark to improve traffic flow by revising traffic controls to protect left turn movements and to restrict pedestrian street crossings with use of walk/don't walk signals. Prior to these improvements heavy pedestrian flows, often jaywalking with little regard for crosswalks and traffic signals, conflicted with and caused significant disruption to traffic flow.

Table B -3. SPEED CHANGES RESULTING FROM REVISING TRAFFIC SIGNALS TO PROTECT LEFT TURN MOVEMENTS AND INCLUDE WALK/DON'T WALK PEDESTRIAN SIGNALS IN NEWARK, NEW JERSEY[a]

Experiment type and number	Direction	Time	Travel speed, mph[b]		Speed increase percent	Table and page no. ref. 3
			Before	After		
Left turn and pedestrian controls:						
A 7 - Newark Raymond Blvd. and McCarter Highway	EB	AM	6.5	10.9	67.7	Table G-32, p. 211
	WB	AM	9.9	12.0	21.2	
	NB	AM	14.0	13.6	- 2.9	
	SB	AM	12.8	14.3	11.7	
	WB	PM	5.5	6.5	18.2	Table G-33, p. 212
	NB	PM	11.9	6.5	-45.3	
	SB	PM	11.0	8.4	-23.6	

[a] Source: Reference 4.

[b] Point-to-point speed, exclusive of delays.

It is observed that the predominant traffic flows (EB in the AM and WB in the PM on Raymond Blvd.) experienced the most significant increases in vehicle speed. Some minor movements experienced speed decreases.

Traffic Control Signals — Improvements categorized as "traffic control signals" include such techniques as network coordination and sequencing of intersections, timing of intervals, improved allocation of green time, progression enforcements and offsets and computer surveillance and control. The potential for improving traffic flow through these techniques depends very much on the current state of the art being practiced and the corresponding baseline conditions prior to the improvement. It is generally considered, however, that well-timed traffic signals together with optimum intersection design of such features as pedestrian controls, curb parking restrictions, bus stop locations, left turn lanes and channelization can substantially improve traffic flow where suboptimum conditions now exist.

Table B-4 summarizes the results of experiments in Newark and in Louisville to improve traffic flow by improving traffic signal operations through progression and coordination. It is observed that traffic signal progression and coordination can have a significant impact on the flow of traffic. In the Newark experiments, travel speed was increased substantially in the predominant flow directions although some decrease in travel speed was observed in the minor flow directions. Similar results were recorded in Louisville where predominant flows on Broadway enjoyed travel speed increases while minor flows on cross streets experienced some travel speed decreases.

Example CO Emission Reductions — Table B-5 shows the estimated potential change in local CO emissions for three experiments conducted as part of the NCHRP research. Present and future CO emissions were calculated taking into account before and after travel time, delay time per vehicle, traffic volumes and average vehicle emission rates.

Table B -4. SPEED CHANGES RESULTING FROM TRAFFIC SIGNAL PROGRESSION AND COORDINATION IN LOUISVILLE, KENTUCKY AND NEWARK, NEW JERSEY[a]

Experiment type and number	Direction	Time	Travel speed, mph[b]		Speed increase percent	Table and page no. ref. 3
			Before	After		
Signal progression:						
B 100 - Newark						
Broad St. (North)	NB[c]	PM	8.9	14.3	60.7	Table 17
	SB[d]	PM	9.9	8.4	-15.2	page 66
B 93 - Newark						
McCarter Hwy	NB	AM	12.7	14.5	14.2	
	SB	AM	13.1	15.3	16.8	
McCarter Hwy (N)	NB[c]	PM	7.4	16.4	121.6	
	SB[d]	PM	12.6	14.2	12.7	
McCarter Hwy (S)	NB[d]	PM	15.7	13.6	-13.4	
	SB[c]	PM	12.8	16.7	30.5	
B 88 - Newark						
Springfield Ave.	EB[c]	AM	11.1	19.1	72.1	Table G-111
	WB[d]	AM	16.4	12.1	-26.2	page 299
	EB[d]	PM	11.2	12.3	9.8	Table G-112
	WB[c]	PM	9.8	12.7	29.6	page 300
Signal coordination						
E 35 - Louisville						
Broadway	EB	AM	19.2	21.1	9.9	Table G-154
	EB	Midday	18.7	19.9	6.4	page 346
	EB	PM	14.4	17.9	24.3	Table G-155
	WB	AM	14.3	15.5	8.4	page 346
	WB	Midday	15.5	14.4	- 7.1	Table G-156
	WB	PM	14.5	11.1	-23.4	page 347
E-W Streets						
So. of Broadway	Avg	AM	21.2	19.3	- 9.0	
	Avg	Midday	22.4	20.3	- 9.4	
	Avg	PM	17.6	15.6	-11.4	
N-S Streets	Avg	AM	17.7	18.0	1.7	
	Avg	Midday	16.5	18.0	9.1	
	Avg	PM	15.8	15.3	- 3.2	

[a] Source: Reference 4.

[b] Point-to-point speed, exclusive of delays.

[c] Predominant direction of flow

[d] Minor direction of flow.

Table B-5. ESTIMATED CO EMISSION CHANGES FOR SEVERAL EXPERIMENTS[a]

Experiment type and number	Direction	Time	CO emissions, Kg		Emissions reduction, percent
			Before	After	
Signal progression					
B 88 - Newark Springfield Ave.	EB	AM	119.1	60.4	49.3
	EB	PM	45.3	41.0	9.5
	WB	AM	33.3	47.9	-43.8
	WB	PM	136.0	88.0	35.3
Truck loading restrictions[c]					
C 123 - Newark University Ave.	Between Lackawanna Ave. and Orange St.	All	29.5[e]	23.7[e]	19.7
Directional control and lane use					
E 31 - Louisville River Road and Fort Nelson Way	NB	AM	35.3	14.9	57.8
	NB	PM	122.8	50.0	59.3
	SB	AM	24.3	25.4	- 4.5
	SB	PM	5.9	5.1	13.6

[a] Calculated by GCA/Technology Division from data in reference 3.

[b] Travel data were presented in Table B -4.

[c] Travel data were presented in Table B -2.

[d] Travel data were presented in Table B -1.

[e] CO emissions expressed in grams/vehicle because traffic volumes are not known

It can be seen that CO emissions can be substantially reduced with the types of measures being discussed here, although in some cases the decreases on one street are partially offset by increases elsewhere.

Examples of Traffic Redistribution

Measures to redistribute traffic flow throughout a street and highway network have been discussed or proposed,[6,7,8] but have been implemented only rarely.[9] This section will describe some examples of traffic redistribution programs and their quantitative effects on CO emissions and concentrations. Because of the relative lack of data and experience with traffic redistribution, two of the examples are based upon recent studies while a third is based upon actual implementation.

Several general remarks are in order before presenting the three cases. First, carbon monoxide concentrations were estimated in each of these studies by methods that are different from the screening guidelines. Exact quantitative results would be expected to be different for different methods, but the conclusions are expected to be the same by any of the several methods. Second, the results indicated here are for particular circumstances and would differ somewhat with different vehicle fleets, existing traffic conditions, or street networks. Third, two of these examples are based upon "paper studies." They have not been implemented. The presentations are useful for showing the effects of the assumed traffic conditions but the effects predictions would obviously be altered if traffic did not respond as expected.

Providence, Rhode Island — In the course of developing a Transportation Control Plan (TCP) for downtown Providence, R.I., the Rhode Island Departments of Transportation and Health (RIDOT and RIDOH) proposed three alternative traffic flow improvement plans to help reduce excessive carbon monoxide concentrations in the Central Business District (CBD). GCA/Technology Division analyzed the three plans for their effects on CO concentrations through the use of the APRAC-la air pollution model.[10]

The APRAC-1a model calculates CO concentrations and accounts for traffic volumes, speeds, atmospheric conditions and meteorological factors that influence the movement (dispersion) of CO. For a given street network and a given set of meteorological conditions, variations in calculated CO concentrations are a function only of traffic input. Thus, the results of using APRAC in Providence will be used here not to indicate absolute CO concentrations but to show the relative effects of various traffic changes.

The Providence CBD is quite compact and relatively congested. The street network, like many others in older New England cities, is irregular. It includes many streets that have only one or two moving lanes of traffic, through streets with curb parking, several one-way streets, and a great deal of pedestrian interference. The traffic flow thus tends to be characterized by low average speeds and substantial queuing, especially in peak hours.

The three alternative traffic flow improvements proposed for study by RIDOT and RIDOH can be described as:

1. Installation of a computerized traffic signal system in the CBD.

2. Intermediate redistribution of traffic, including traffic signal improvements (same as (1) above), one new street to be one-way, and selected intersection and parking changes.

3. Creation of a vehicle-free zone by closing several streets to traffic, plus associated traffic flow changes and installation of computerized signals.

Each of these alternatives will be discussed for their expected impacts on CO levels. Other impacts will be presented later. For a more detailed explanation of these measures the reader is referred to the consultant's report[11] on the TCP.

Alternative no. 1: computerized traffic signal system — This alternative involves a computer-operated traffic signal coordination system. Six intersections within the CBD would be computerized, and four outside the CBD. Traffic signal changes were not forecasted to redistribute traffic volumes, but only to increase speeds on a number of streets and reduce speeds on a few streets. Total vehicle-miles of travel (VMT) would not be changed. RIDOT forecasted speed increases of 2 to 3 miles per hour on many street sections (links), with most present speeds in the range of 9 to 15 mph. Figure B-2 shows the CBD and indicates where speeds would increase (or decrease).

APRAC analysis showed reduced CO concentrations at 7 out of 20 locations, decreases ranging from 6 percent to 57 percent. Three locations were forecasted to experience higher concentrations, and the rest would be about the same. Perhaps most important, the present peak CO level was forecasted to be reduced by 57 percent. The new peak CO level (at a different location) would be 23 percent below the present peak.*

This example shows that:

- Relatively modest speed increases, if they can be effected and where speeds are rather low, can produce significant reductions in CO emissions, without VMT changes.
- There are always compromises to make. Increasing speed on some streets usually necessitates reduced speed on others. In this case, CO levels would be expected to increase at several locations.

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*That is, the particular location that has the highest CO reading in the present situation is forecasted to have 57 percent lower CO levels after the improvement, but a different location will then have the highest CO level, which will be only 23 percent below the present maximum CO level. In this particular case, the new peak CO level is at a location whose CO level does not change; it is the same in the before and after cases.

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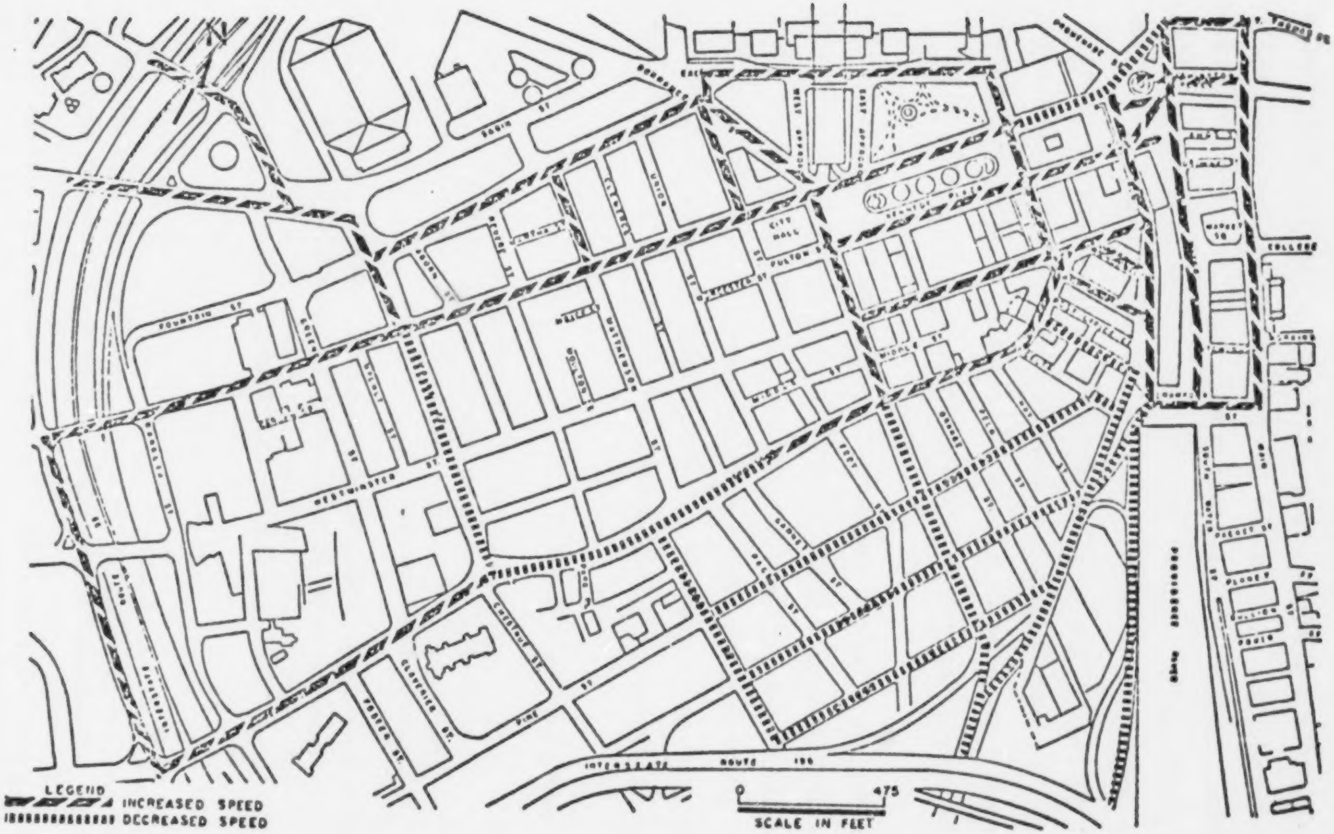
LEGEND
INCREASED SPEED
DECREASED SPEED
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SCALE IN FEET
INTERSTATE ROUTE 195
CITY HALL
FULTON ST
WESTMINSTER ST
FOUNTAIN ST
UNION
PINE ST
CLEMENCE ST.
FOSTER ST.
PROVIDENCE RIVER

Figure B -2. Impact of computerized traffic signal system in Providence, R.I.[11]

- The problem may only be reduced, not eliminated. The Providence analysis showed a reduction in CO levels of only 23 percent, between the present highest level and the forecasted highest level with the improvement, even though the present highest level was reduced 57 percent at the same location. (The amount of reduction needed in Providence was over 50 percent.)

Alternative no. 2: intermediate traffic redustribution — This alternative would attempt to redistribute traffic flow so that portions of some streets would experience a net reduction in traffic volume (and emissions of CO). The components of this would be (see Figure B -3):

1. Make Dorrance Street one-way from Weybosset Street to Kennedy Plaza.
2. Redesign of Memorial Square intersection.
3. Buses now utilizing Dorrance Street south from Westminster Street to be rerouted from Westminster Street north through Kennedy Plaza.
4. Elimination of approximately 16 on-street, metered parking spaces on the south side of Kennedy Plaza.
5. Installation of a computerized traffic signal system for the CBD.

Figure B -3 shows how traffic volumes would be affected. Six streets would experience increased traffic volumes, while two would experience a decrease, according to RIDOT forecasts. Total travel (VMT) would increase by 0.5 percent.

APRAC predicted that CO levels would be changed in about the same way as for Alternative No. 1, except where substantial volume changes occurred. In the vicinity of Dorrance Street, which is to be made one-way, CO levels were predicted to be reduced by nearly 50 percent. The location now experiencing the highest CO level, (corner of Washington and Dorrance Streets) would experience reductions of 49 percent. The highest level in the network would be 21 percent less.

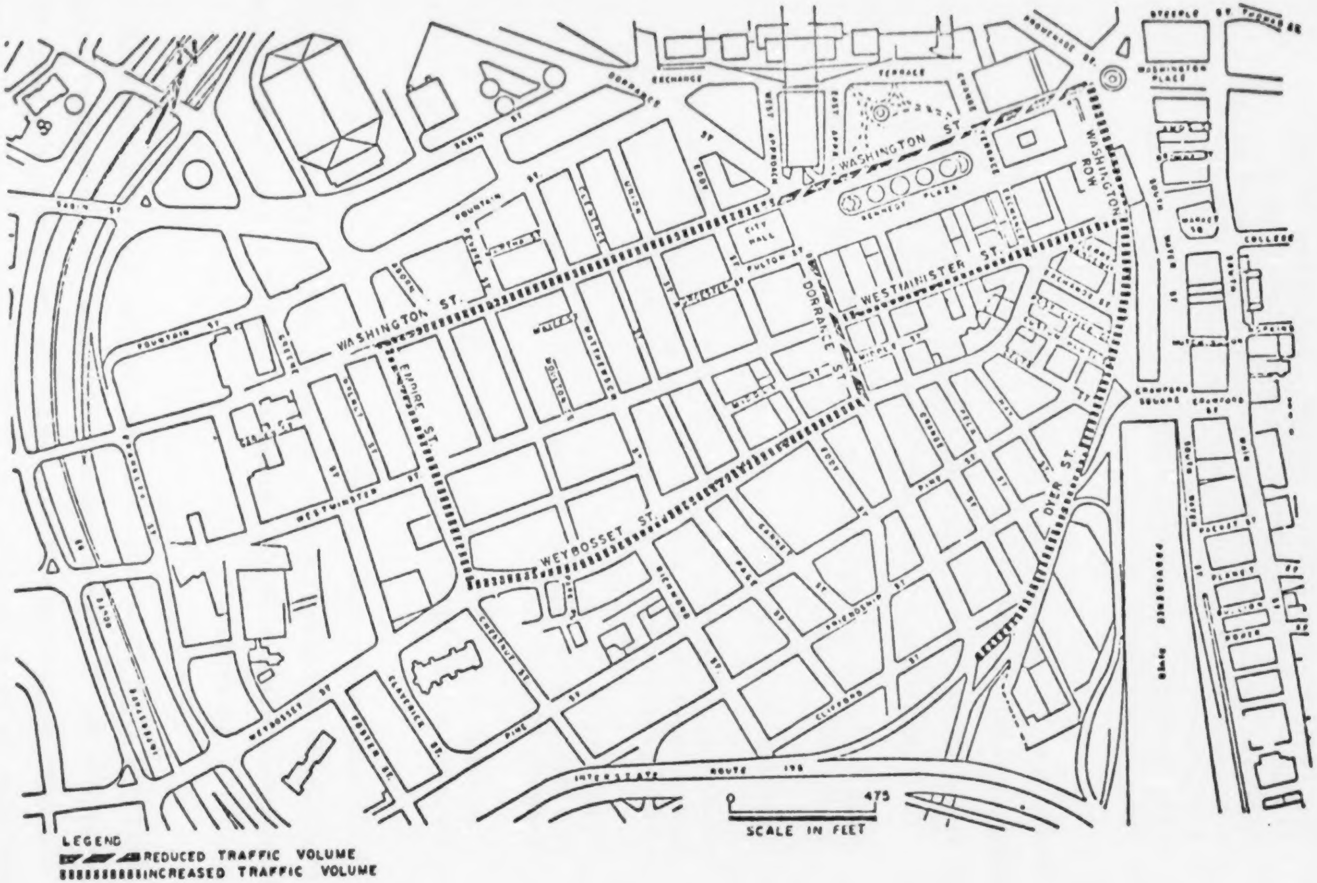
WASHINGTON ROW
WASHINGTON ST.
KENNEDY PLAZA
CITY HALL
WESTMINISTER ST.
DORRANCE ST.
WASHINGTON ST.
EMPIRE ST.
WEYBOSSET ST.
DYER ST.
PROVIDENCE RIVER
SOUTH WATER ST
INTERSTATE ROUTE 195
475
SCALE IN FEET
LEGEND
REDUCED TRAFFIC VOLUME
INCREASED TRAFFIC VOLUME

Figure B-3. Impact of intermediate traffic restribution, Providence[11]

As before, this example shows the effect of modest speed changes can be significant. In addition:

- One-way streets are expected to be useful for reducing local CO concentrations, so long as there are suitable alternative routes for the reverse flow and so long as total travel is not increased enough to cause significant increases in VMT or emissions. When one-way streets are used, volumes and CO levels will increase elsewhere.

Alternative no. 3: vehicle free zone — This alternative would involve closing certain streets to traffic, rerouting of traffic in a manner similar to Alternative No. 2, and installation of better traffic signals. In particular, the components of this strategy would be:

1. Closing off the following streets to traffic:
    - Westminster Street, from Dorrance Street to Canal Street.
    - Dorrance Street, from Dorrance Street to Westminster Street.
    - Exchange Terrace, from south side of Kennedy Plaza to Westminster Street.
2. Redesign of Memorial Square intersection.
3. Rerouting of buses now utilizing Westminster Street and centralization of bus stop locations within a one-block range in Kennedy Plaza.
4. Elimination of approximately 20 on-street, metered parking spaces in the following locations:
    - South side of Kennedy Plaza (16)
    - Friendship Street (4)
5. Installation of a computerized traffic signal system for the CBD.

Figure B-4 is a map showing the sections of each street affected.

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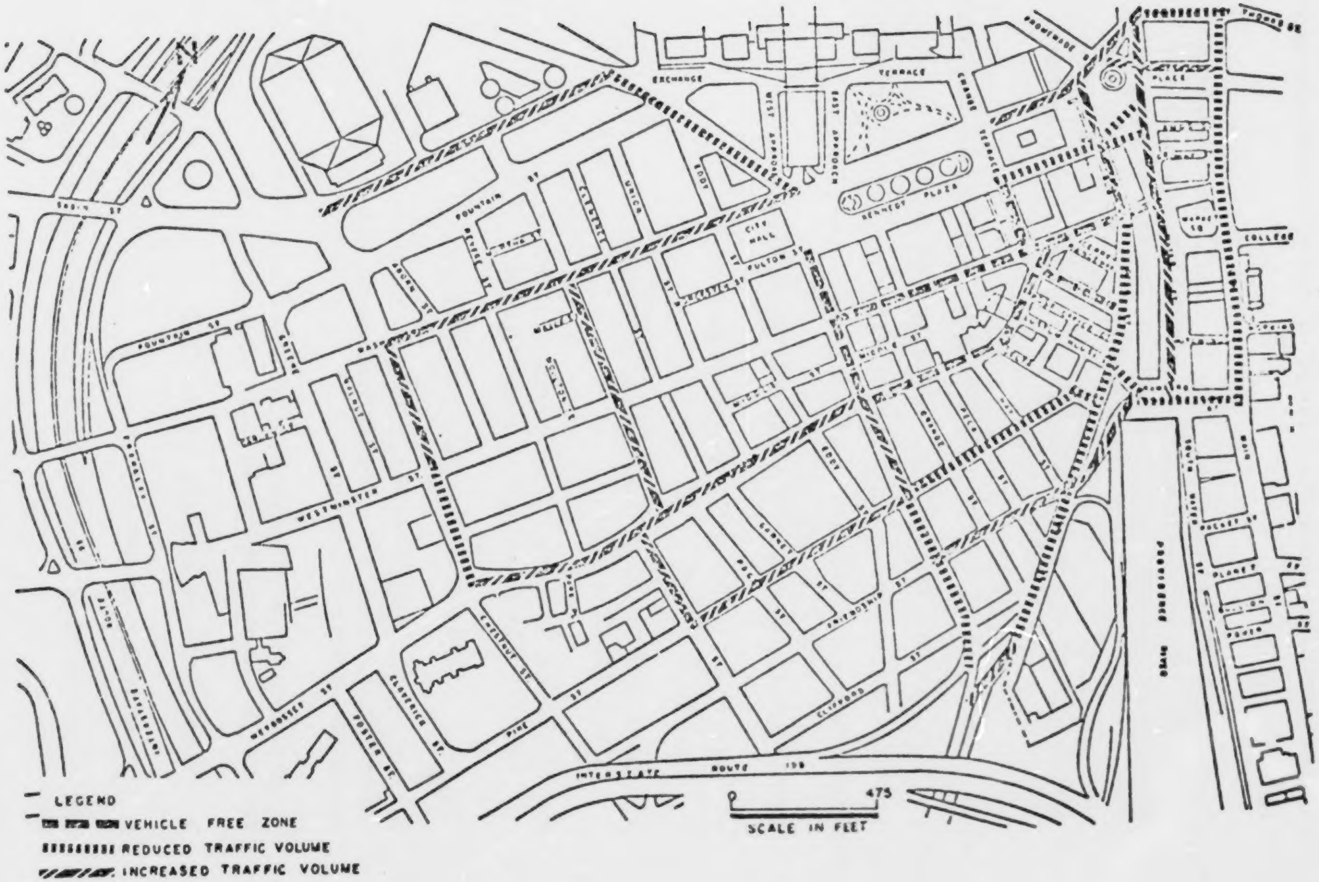
EXCHANGE
TERRACE
EAST APPROACH
WEST APPROACH
KENNEDY PLAZA
CITY HALL
FULTON ST
EDDY
UNION
FOUNTAIN ST
WESTMINSTER ST
WEYBOSSET ST
CHESTNUT ST
PINE ST
FOSTER ST
CLIFFORD
PROVIDENCE RIVER
COLLEGE
MAIN
SOUTH WATER ST
INTERSTATE ROUTE 195
0
475
SCALE IN FEET
LEGEND
VEHICLE FREE ZONE
REDUCED TRAFFIC VOLUME
INCREASED TRAFFIC VOLUME

Figure B -4. Impact of a Vehicle Free Zone in Providence[11]

This improvement would involve closing four street sections with a total length of 2500 feet. Closing the streets, which are among the busier streets in the Providence CBD, would divert traffic to other streets. Total travel (VMT) is forecasted to increase by 0.3 percent. Speeds are expected to be approximately the same as for Alternatives 1 and 2, except in the Vehicle Free Zone.

Because of the traffic redistribution, several locations were calculated by APRAC to experience increased CO levels, although the worst present location (Washington and Dorrance Streets) would be improved. The CO level at the present worst location would be decreased by 54 percent. The new peak CO level would be 32 percent below the present peak level. Two locations were forecasted to be exposed to new CO levels that are between 190 and 220 percent higher than before at those same locations, and a third would experience an increase of 47 percent. These increases resulted from predicted volume increases.

The implications of this example are:

- If properly planned, major traffic redistribution schemes can achieve reductions in peak CO levels.
- Redistribution will cause increases in travel volumes on some streets, may decrease speeds, and will likely increase emissions in some areas. Whether these CO increases are tolerable depends upon the local situation.

Such alternatives as these might be suitable in one location but not in another. Whether or not they are suitable depends upon the actual volumes, speeds, and CO levels. Some locations would be expected to experience increases in CO levels as a result of any of the above three alternatives. Clearly such increases cannot be tolerated if they would cause a violation of the National Ambient Air Quality Standards (NAAQS's). (Also, non-air-quality considerations affect the decision, as will be discussed later.)

Springfield, Massachusetts – Springfield, in Western Massachusetts, is another city with violations of CO standards that is planning to use traffic redistribution as part of the solution. The proposed improvements discussed here were developed by GCA in conjunction with EPA and State and local agencies.

The particular significance of the Springfield example is that the traffic data was developed in detail. A special origin-destination survey of the CBD was performed in order to develop an accurate data base for traffic flow analysis. Postulated traffic flow changes were evaluated after traffic was manually redistributed in the analysis, using the knowledge of detailed origin-destination patterns for the CBD.

The APRAC-la model[10] was again used in the air quality analysis. In this case, APRAC was run only for the recommended improvement plan.

Background – Analysis of air quality in downtown Springfield indicated that several specific locations now experience excessive concentrations of carbon monoxide. In order to determine the nature of the vehicular traffic, a study of existing traffic characteristics was performed. From the traffic study it was concluded that low speeds and interruptions to traffic flow along Main Street, the most heavily-traveled roadway are caused primarily by pedestrian-automobile conflicts, marginal friction resulting from the occupancy of curb-lanes by busses and illegally parked or standing vehicles, and friction resulting from conflicting vehicle movements (left-turns and cross traffic). Traffic flow on portions of State Street, which runs perpendicular to Main Street, is often impeded by illegally parked vehicles and by conflicting turning movements, as well as a result of capacity constraints at various points along the street. It was also indicated by the study that, while Main Street and State Street were operating at or near capacity, other important streets in the area appeared to have abundant reserve capacity available. This was important to later choice of control measures.

It was decided that Main Street should become the focal point of consideration for developing any areawide traffic control measure for two reasons. First, the most severe carbon monoxide pollutant problems were shown to exist on Main Street; and second, person-exposure potential in the area was highest along Main Street, because it is a major shopping and employment street.

Several basic improvement concepts, each involving circulation changes of various configurations, were considered. The first involved creating a vehicle-free zone along Main Street. While this measure would have several very positive aspects regarding environmental quality, it was considered that the loss in capacity of north-south vehicular flow would pose serious consequences elsewhere.

A second alternative was to convert Main Street to one-way operation. It appeared that this would have good potential to decrease vehicular traffic on the street and consequently result in higher operating speeds as well. Further analysis indicated that other compatible measures could be implemented to enhance the benefits derived from conversion of Main Street to one-way operation.

A third concept involved maintaining two-way operation on Main Street but implementing other measures such as reducing vehicular conflicts. While this was considered to be the least disruptive measure, it also would be the least effective in improving air quality on Main Street.

From the above analysis it was decided that the second alternative (one-way traffic on Main Street) would provide the best solution to the air quality problems on Main Street. Therefore this concept was expanded to include a number of additional elements, which together form the recommended traffic flow improvement plan.

Traffic flow improvement plan — The traffic flow improvement plan is composed of several interrelated elements. The objective of the plan is to effect a redistribution of traffic on the downtown street system by means of a revised one-way circulation pattern augmented by other measures such as limited street closings, turn prohibitions, parking restrictions, and others.

It was recommended that Main Street be converted to one-way operation in the northbound direction, in the general vicinity of the CBD. In theory, converting the street to one-way operation will decrease the existing traffic volumes and, at the same time, increase the available capacity of the street, therefore allowing smoother flow and improved operating speed. Figure B-5 shows the recommended traffic pattern changes. In order to further reduce interference to flow on Main Street as well as to discourage random circulation (i.e., driving around the block in search of curb parking, etc.) it was recommended that a number of other adjacent streets also be converted to one-way operation or partially closed* to general traffic. Associated parking changes, signal adjustments, and improvements in channelization and traffic control devices were also recommended.

The method for assessing the plan involved first determining its impact on traffic volumes for each street segment (link) in the downtown. This was accomplished through a traffic assignment technique that involved predicting travel paths through the downtown under different circulation patterns. The traffic assignment technique was based on actual trip data derived from the downtown traffic survey. With the origins and destinations known, probable travel paths among all combinations of origins and destinations were determined through a manual process. Once

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*Short street segments were to be closed to through traffic but left open for commercial vehicle loading and emergency use.

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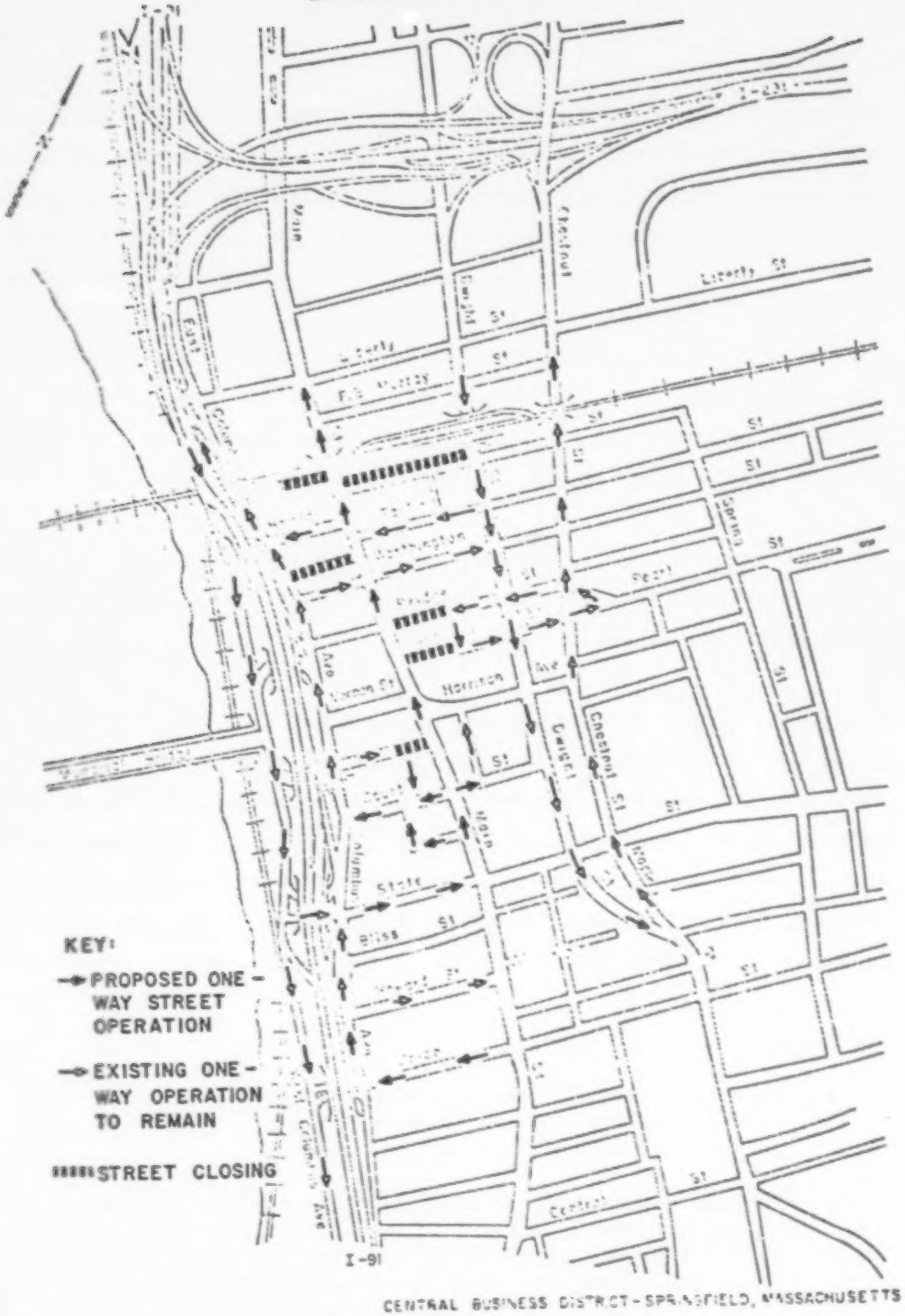
I-91
I-291
Main
Dwight
Chestnut
Liberty St
Liberty
St
Worthington
Pearl
St
Spring
Harrison
Ave
Court
Main
Dwight
Chestnut
St
State
Bliss
St
Columbus
Ave
Central
St
I-91
KEY:
PROPOSED ONE-WAY STREET OPERATION
EXISTING ONE-WAY OPERATION TO REMAIN
STREET CLOSING
CENTRAL BUSINESS DISTRICT-SPRINGFIELD, MASSACHUSETTS

Figure B-5. Proposed traffic circulation system, downtown Springfield, Massachusetts[12] changes in link volumes were established, the new link volumes were compared with existing volumes and this, along with estimates of downstream characteristics that might affect flow, became the basis for judging whether the link speed would change so significantly that a new speed should be assigned. This process was repeated for three configurations of one-way streets and supportive measures, after which the recommended improvement was decided upon. The volumes and speeds determined for the recommended plan were entered into the APRAC computer model to derive estimates of resulting carbon monoxide concentrations at the 20 locations used to assess existing air quality in downtown Springfield.

For more complete description of the Springfield area, its air quality situation, the recommended improvements and resulting analysis, the reader is referred to the consultant's report.[12]

Changes in carbon monoxide levels calculated by APRAC showed that effects would vary widely around the CBD. CO levels were reduced in several locations, by up to 83 percent. In other locations, CO levels would increase by up to 138 percent, primarily because of increased travel on some streets, most significantly, CO levels at the present worst location (Main at Hillman) would be reduced by 72 percent. The new highest CO level would be 19 percent below the previous maximum.

The Springfield study showed:

- Peak CO concentrations can be reduced considerably by actions that increase speeds or reduce traffic volumes, such as one-way street systems.
- Traffic redistribution will increase traffic volumes, emissions, and CO levels. Whether this type of effect is acceptable will depend upon local conditions and especially upon the absolute CO levels. (This re-affirms the Providence case, described earlier.)

- Planning the redistribution of traffic in a CBD warrants detailed, expert consideration of all the associated traffic flow changes, including safety, parking, traffic control devices, and others accurately forecasting the effects of redistribution is facilitated by current origin-destination information in the CBD.

It is worthwhile mentioning that in both Providence and Springfield, the traffic flow changes by themselves were calculated to be insufficient to meet air quality standards. Additional control measures would be needed.

Trenton Commons — Dozens of U.S. cities, and many more in Europe, have considered, planned, or implemented some form of vehicle-free zone. These areas are also referred to as auto control zones, traffic-free zones, pedestrian malls, or transit malls, and are usually formed by closing selected downtown streets to normal traffic. Many such vehicle-free zones (VFZ's) are in shopping districts and were intended to increase the economic vitality of an area, not specifically to control air pollution. The VFZ concept has also been suggested as a CO control measure because it removes traffic from congested areas. Both Springfield, Mass., and Providence, R.I., just mentioned, are among several cities recently considering a VFZ for CO control purposes.[13]

Although several VFZ's have been in operation for substantial periods of time, there is little detailed data on the effect of such VFZ's on traffic conditions or on air pollution. One study has recently been published, however, that includes before-and-after traffic data and air pollution calculations for the VFZ in Trenton, New Jersey.[14]

The Trenton Commons is a VFZ two blocks long in the Trenton shopping district, opened in September 1974. The Commons was developed as a stimulus for downtown shopping activity. The section of State Street converted to a pedestrian zone was formerly an arterial carrying an AADT of 15,000 vehicles/day. During the same period when the Trenton Commons was constructed and opened, one parallel street was widened and another parallel street was changed from two-way to one-way operation. There are plans to implement additional improvements on nearby streets and intersections and to modernize the traffic signal system, but these actions have not yet been undertaken.

In the report analyzing the effect of the Trenton VFZ, comparisons were made of speeds, volumes, and carbon monoxide emissions in the before and after cases. Total vehicular travel (vehicle-miles of travel) within the study area around the Trenton Commons was found to have decreased by 5.4 percent from 1972, before construction began, to 1974, after the VFZ was opened. Average vehicular speeds increased by 10 percent, which was judged not to be a significant change (this amount of change is within the error of estimating speeds). It was concluded that changes in the circulation system resulting from the Trenton Commons could have reduced actual vehicular emissions of CO by smoothing the flow of traffic but that the reduction could not be quantified with the available data.[15] The reduction in VMT reduced CO emissions, but the reduction could not be directly attributed to the VFZ.

An analysis was also made of the localized effects of the VFZ on CO emissions. Adjacent to the Commons, emissions were calculated to have been reduced by 74 percent by the VFZ, which one would expect. This was roughly confirmed by air quality monitoring that showed reductions in CO levels of 64 percent between 1972 and 1974. (Part of that reduction resulted from newer, less-polluting vehicles that entered the vehicle population between 1972 and 1974.) The monitoring station is on State Street, within the Trenton Commons VFZ.

At other locations in the CBD, CO emissions were calculated to change because of the VFZ. Some locations were improved, some were degraded, depending upon the specific changes in speeds and volumes. Significantly, no location was estimated to have emission densities after the VFZ was created as high as did the State Street area before the VFZ; that is, the worst-case CO concentrations in the CBD were apparently lower with the VFZ than without. After accounting for the effect of newer vehicles, it appears that the traffic redistribution due to the VFZ had the effect of reducing maximum CO concentrations.

In summary:

- Available data does not clearly demonstrate any overall effect on VMT or speed that can be attributed to the Trenton Commons VFZ.
- Emissions of CO and resulting air quality were substantially improved within the VFZ itself, as would be expected.
- Changes in CO emissions and estimated CO concentrations with the VFZ were highly specific to the local traffic conditions; some locations were improved, while others were degraded. Generally, the redistributed traffic produced lower maximum CO densities. Some of the improvement must be attributed to the use of newer vehicles, but some apparently is the result of the VFZ.

Summary, Air Quality Effects of Traffic Engineering Measures

The several examples presented here have shown that both traffic flow improvements and traffic redistribution measures ban have substantial positive benefits to the control of CO levels. The examples have also shown that control measures cannot be chosen arbitrarily. Their effectiveness depends upon the present situation. Some measures produce negative air quality effects that must be evaluated. And all involve the additional considerations of cost, social and economic effects, and other aspects of implementation. These latter types of concern will be discussed next.

ISSUES ASSOCIATED WITH IMPLEMENTATION OF TRAFFIC CONTROL MEASURES

Introduction

Measures to improve the flow of traffic have consequences in addition to their intended effect of reducing CO concentrations. It is necessary to identify the desirable and undesirable impacts of alternative measures so that those responsible can (1) choose among alternative means for attaining the air quality standards and (2) take into account, plan for, and minimize undesirable and maximize desirable tradeoffs between improvements in air quality and the other impacts, where possible. These considerations add another dimension to the required analysis and aid in the decision-making process.

Selection of CO control measures is no different from other kinds of planning in this respect. The same types of economic and environmental issues must be addressed, and the procedures can be the same. The type and degree of analysis will depend upon the circumstances, and of course should be related to the magnitude of the impacts.

This Guideline will not attempt to describe a special planning process for CO control measures, because existing decision-making processes can be used. Rather, this Guideline will attempt to perform two functions. First, it will provide examples of the non-air-quality issues that may arise in connection with certain control measures. Second, it will discuss the special aspects of decision-making that result from the goal of attaining air quality standards.

The impacts to be discussed have been differentiated in various ways. For the present purpose, the discussion will use the following categories of effects:

- Social and economic impacts
- Institutional impacts
- Macroscale travel effects.

Social and Economic Impacts

For discussion, it is useful to distinguish the social impacts from the economic impacts. Although it is acknowledged that this is often a difficult distinction to perceive, it is considered that the segregation is beneficial in terms of understanding the issues. Social impacts include the advantages and disadvantages - pecuniary and nonpecuniary - that affect residents as individuals. Thus, any changes in prices, taxes, or mandatory expenditures along with subjective changes in lifestyle are included under social impacts. Economic impacts refer to the effects, mainly pecuniary, which affect the city or business establishments as legal entities. The types of cost most often referred to under economic impacts are capital costs and annualized costs. Capital costs are defined as those expenditures for plant and equipment. Annualized costs are those expenditures associated with the yearly operation and maintenance (including depreciation) of the capital equipment.

It is important to note that the quantification of costs and benefits is not possible in every instance. This may be due either to lack of information or, more basically, to the fact that certain items are not allocated by the market mechanism and hence lack an assigned monetary value. In those instances where quantification is not possible or reasonable, qualitative assessments should be presented. Thus, even though all significant parameters may not be quantified, they should be identified.

The following discussion presents the results of an example socioeconomic analysis of the consequences of the three alternative traffic flow improvements proposed for the previously discussed Rhode Island TCP. The purpose is to illustrate the level of detail appropriate for the analysis, types of impacts considered, and an order of magnitude of the potential impacts.

The three alternative traffic flow improvement schemes are as follows:[*]

1. Installation of a computerized traffic signal system in the Providence Central Business District.
2. Dorrance Street improvement, with associated changes to Memorial Square and rerouting of buses.
3. Creation of a Vehicle Free Zone, with certain streets closed or made one-way and associated changes in parking and traffic signals.

The following discussion is taken substantially from Reference 11.

Analysis of Example Alternative No. 1: Computerized Traffic Signal System - This alternative would involve a computer-operated traffic signal coordination system. Six intersections within the CBD, and four outside, would be affected by the plan now being considered. Refer back to Figure B-2 for a map showing the street sections affected.

Social impacts — The installation of a computerized traffic signal system in isolation from the other improvements, such as the Vehicle Free Zone and Dorrance Street rerouting, would have minimal social impact. Computerized signalization would generally serve to increase travel speeds in the downtown core from approximately 9 miles per hour to 12 miles per hour, thus reducing travel time through the core area by a factor of one-fourth. A computerized traffic signalization system would also serve to reduce the incidence of stop-and-go travel conditions, particularly along Washington Street. At present, the Washington Street signals are old, manually set signals that are usually out of phase with each other. As a result, traffic on Washington Street is slowed down, with vehicles required to stop for each traffic light. The major result of the computerized signalization would be to bring Washington Street up to a par with other major arteries in the downtown area.

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[*] Note that these are the same as the Providence examples cited earlier, where the traffic and air quality impacts were also presented.

In summary, the computerized traffic signal system would tend to improve traffic flow through the downtown core area. The major result would be to improve travel conditions for drivers, and to increase the safety of pedestrian crossings.

Economic impacts — The City of Providence is now receiving bids for a Computerized Traffic Signalization system. The mean of the cost estimates received to date relative to the installation of a master minicomputer system is approximately $500,000. Based on discussion with the City Traffic Engineer, Phase I of a signal installation program could be in effect by 1977. Phase I of such a program assumes that 10 intersections would be computerized, at a cost of $25,000 per intersection. It is assumed that 6 of these 10 intersections would be within the Central Business District. On this basis, the total capital cost of this project is estimated to be $650,000. Federal funding would be sought by the City for 70 percent of project cost. The Traffic Engineering Department anticipates that operation of the system would be absorbed within the present workload of the Department. At a maximum, one additional engineer would be required.

A summary of costs is presented in Table B-6. Total capital cost is estimated to be $650,000, of which the City would be responsible for

$195,000. The present* thinking of the Traffic Engineering Department is that the City would use a portion of its allotted Community Development funds in order to provide the City's matching share. It should be noted that a total of $500,000 in Community Development monies have been allocated for Downtown, and there is tremendous competition among projects; thus, the use of CD money for this purpose is by no means certain. Estimated annual operating cost, assuming an additional engineer at $10,500 per annum, is $10,500 - exclusive of existing staff and administrative expenses.[11]

Table B-6. TRAFFIC SIGNAL IMPROVEMENT PROGRAM COSTS

Cost element		Cost
I. Capital cost		
• Mini-computer system		$500,000
• 6 computerized intersections		150,000
Total		$650,000
70% Federal	$455,000	
30% City	195,000	
II. Annual operating cost		
• 1 engineer @ $10,500 per annum		$10,500

Analysis of Example Alternative No. 2: Intermediate Traffic Redistribution - As described earlier, this would be a traffic redistribution scheme, using a major one-way street and associated traffic engineering changes. (Refer back to Figure B-3 for the travel changes.)

Social impacts — The objective to be served by making Dorrance Street one way from Weybosset Street to Kennedy Plaza is to reduce the potential for automobile, bus, truck, and pedestrian conflict, particularly at the Dorrance Street-Weybosset Street intersection.

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*At time of Reference 11 (Spring 1975).

Under present conditions, vehicles traveling south on Dorrance Street and making a left turn onto Weybosset exacerbate an existing traffic problem, in that turning vehicles must compete with oncoming traffic. Among the factors that contribute to the congestion and stop-and-go conditions in the vicinity of this intersection are the following: (a) competition between buses and auto and truck traffic; (b) lack of synchronization in traffic signalization and flow through Memorial Square, Kennedy Plaza, Washington Street, and Dorrance Street; (c) competition between pedestrians and vehicular traffic; and (d) narrowing roadway conditions on Weybosset Street. By making this section of Dorrance Street one way - in combination with the proposed computerized traffic signalization and redesign of Memorial Square - many of these factors would be addressed.

To the extent that the traffic flow measures would serve to reduce the incidence of stop and start travel, increase travel speeds, reduce congestion, improve air quality, and improve the safety and amenity of the area for pedestrians, the social effects of these measures would be positive. Potentially negative effects that must be considered as well are the requirement that drivers adjust to alternative travel routes in the short run. Associated with alternative routing, most drivers would be subject to minor increases in trip time and distance for certain trips - in particular, for trips requiring the use of lower Weybosset Street. In addition, the one-way routing of Dorrance Street would require that many heavily used bus routes be rerouted through Kennedy Plaza, and that bus riders become adjusted to such revisions in the short run. It is expected that the above-mentioned potentially negative effects would generally be true only in the immediate short run; and in the longer run, drivers, transit users, and pedestrians would readily adjust to the new travel patterns. On this basis, the social impacts of the traffic flow measures listed under Dorrance Street Improvements would generally be positive. Effects that would be true also in the long run are the associated minor increases in trip distance and time, and the slightly reduced accessibility of lower Weybosset Street to vehicular traffic.

The Dorrance Street traffic flow improvement package would serve to increase travel speeds through the downtown from approximately 9 miles per hour to 12 miles per hour. This effect would be due chiefly to the installation of the computerized traffic signal system, and not to the one-way routing of Dorrance Street. For this reason, this effect was discussed in the evaluation of Alternative No. 1, Computerized Traffic Signal System. The Dorrance Street rerouting would, however, help to reduce the incidence of stop and start traffic, and would thereby assist in reducing vehicular emissions, particularly at the Dorrance Street-Weybosset Street intersection. The street rerouting would also serve to reduce the incidence of vehicle/pedestrian accidents that are a relatively frequent occurrence at the Dorrance-Weybosset intersection. Another problem area, in terms of vehicle/pedestrian accidents, is Memorial Square. The redesign of this intersection as well would have beneficial effects from the standpoint of reducing vehicle/pedestrian and vehicle/vehicle conflicts.

By making Dorrance Street one way, vehicles that are presently traveling south on Dorrance Street and making a left turn onto Weybosset would be required to use alternative routes in order to reach their destinations. In addition, vehicles that are presently traveling south on Dorrance Street to destinations east of Weybosset Street (such as Interstate 195) would be required to use other routes. The two major alternative routes that would be used instead of using Dorrance Street southbound are: (a) Washington Street to Empire Street to Weybosset Street, and (b) Dyer Street. The changes in trip distance and travel time associated with use of these routes are indicated in Table B-7. From this table it can readily be seen that trips coming through Memorial Square and Kennedy

Plaza to destinations at Turks Head Square would be increased in length by approximately 1/4 to 1/2 mile, or by 1-1/2 to 3 minutes, assuming a travel speed of 12 miles per hour. In terms of increases in gasoline consumption or increases in motor vehicle-related expenditures, this effect would be of minor significance even for drivers who currently make this trip daily. The daily per capita increase in expenditures would amount to about $0.05 per day.[*]

Table B-7. TRAVEL TIME AND DISTANCE: THREE ROUTES - MEMORIAL SQUARE TO TURKS HEAD SQUARE

Route	Distance traveled, feet	Travel time at 12 mph, minutes
Via Dorrance St.	2400	2.27
Via Washington and Empire St.	5500	5.21
Via Dyer St.	3800	3.60

An additional effect of making this section of Dorrance Street one way would be the need to reroute buses that are now traveling south on Dorrance Street. With the exception of the Eddy-City Line and Eddy-Gaspee Plateau routes, most buses could be accommodated by redirecting bus traffic north on Dorrance Street to Kennedy Plaza. Only the Eddy Street bus route would actually have to be relocated.

(At this point, the specific bus routes to be affected were identified.)

It should be noted that the physical ability of Kennedy Plaza to accommodate the additional buses (and associated bus queuing) may be limited. While elimination of parking on the south side of Kennedy Plaza would partially solve this problem, analysis of the physical capacity of Kennedy Plaza relative to the scheduling and number of buses requires further study beyond the scope of this report. A positive social effect associated with the bus relocation would be the centralization of bus stop locations at Kennedy Plaza. This measure would facilitate transfers from one bus route to another, and would be a step toward the consolidation of public transportation services in the vicinity of Union Station.

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[*] Assumes expenditures for maintenance and repairs at $0.07 per mile; and fuel consumption of 14 mpg at $0.58 per gallon.

In summary, the Dorrance Street traffic flow improvements package would have positive social effects in terms of improved traffic flow, improved air quality, and improved safety and amenity for pedestrians. While the one-way routing of Dorrance Street would require short-run adjustments of travel patterns on the part of drivers and transit users, these effects would be reduced in the longer run, and would not appear to be significant deterrents to the implementation of this strategy option.

Economic impacts — On preliminary analysis, the costs associated with the Dorrance Street traffic flow improvements package are due mainly to two capital projects: (1) the installation of a computerized traffic signal system for the Central Business District, and (2) redesign of Memorial Square. It is expected that the posting of Dorrance Street for one-way traffic and the rerouting of buses from Westminster Street north through Kennedy Plaza could be accomplished by existing manpower, and would not require any significant expenditure over and above the present administrative overhead of the responsible city and state agencies. Bus rerouting would necessitate the revising and reprinting of route maps and public informational literature available from RIPTA.

Table B-8 contains the estimated cost for the computerized traffic signal system and for Phase I of a redesign of Memorial Square. The cost of the computerized traffic signal system includes the cost of installing a master computer, installing six traffic signals downtown, and hiring one additional staff member in the City Traffic Engineering Department. The Memorial Square redesign assumes that two traffic signals (distinct from the computerized system) would be installed by 1977. It should be noted that a physical redesign of Memorial Square is not currently contemplated by the City of Providence. If such redesign were to be considered, detailed traffic and engineering studies would be required before a preliminary cost estimate for this project could be developed. If Memorial Square were assumed to be a "typical" intersection, then the capital cost of a Phase II redesign could charge from $50,000 to $100,000 as a base estimate.

Table B-8. CAPITAL AND OPERATING COSTS: INTERMEDIATE TRAFFIC REDISTRIBUTION PACKAGE, PROVIDENCE

Cost element	Cost
I. CAPITAL COST	
Installation of master mini-computer system[a]	$500,000
6 computerized signals[b] @ $25,000 each	150,000
2 traffic signals @ $15,000 each	30,000
Total, capital cost	$680,000
State share (30%): $204,000 Federal share (70%): $476,000	
II. OPERATING COST	$ 10,500
(1 traffic engineer @ $10,500 per annum)	
III. ANNUALIZED COST	$ 32,940
(Includes depreciation of capital @ 10% for 10 years = $22,440)	

[a] Based on mean of cost estimates submitted to Providence Traffic Engineering Department.

[b] Assumes that 6 of the 10 signals planned for Phase I would be installed in the CBD.

As can be seen from Table B-8, the capital cost of the Dorrance Street traffic flow improvement package is estimated to be $680,000. It is expected that federal financial assistance would be sought from the Federal Highway Administration (Urban System funds) to cover 70 percent of these costs. Annualized cost, including depreciation of capital, is estimated to be $32,940.[11]

Analysis of Example Alternative No. 3: Vehicle Free Zone - As described earlier, this Alternative would create a vehicle-free zone on about 2500 linear feet of what are now downtown streets in Providence, plus utilize the computerized traffic signals of Alternative No. 1. (Refer back to Figure B-4).

Social impacts — The creation of a Vehicle Free Zone in the Dorrance, Westminster, and Weybosset Street area would have positive social impact upon residents, workers, shoppers, and visitors to the downtown. Assuming that the majority of functional requirements (such as bus routing, traffic flow, parking, goods delivery and pick-up, rubbish collection, emergency vehicle access, etc.) could be resolved and incorporated into a physical plan, then normal retail service and office functions could be expected to continue simultaneously with the physical enhancement of the area.

The major social benefits resulting from creation of the Vehicle Free Zone include the increased health and welfare effects associated with reduction in air pollution; reduced noise levels; increased amenity and aesthetic enhancement; increased personal safety; reduction in pedestrian vehicle accidents and conflicts; and provision of an environment more conducive to pedestrian activity and leisure. An additional benefit that could potentially result is the creation of a more diverse, higher quality environment, as merchants responded to increased pedestrian activity by expanding and upgrading their merchandise, and additional investments of private capital were made in the downtown.

The Central Business District of Providence currently has an organizational clarity and compactness of scale that makes it amenable to pedestrian travel. (Maps presented additional data in the TCP report.) The CBD has identifiable visual and physical boundaries, consisting of Union Station to the north, the Providence River to the east, and Interstates 195 and 95 to the south and west. Within this area, there are two defined centers - a retail center, located around Westminster Mall, and an office center, culminating at Turks Head Square. The CBD is less than 3,900 feet from side to side (equivalent to a 15-minute walk at 3 miles per hour) - and thus is notable for its pedestrian scale. Although there are heavy pedestrian flows in key areas in the CBD - notably along Dorrance Street, from Kennedy Plaza to Westminster Street, and between the Turks Head Square office building and the Outlet Department Store and Westminster Mall - the sentiment of the downtown business community is that the bulk of purchasing power of the office worker market is presently untapped. By enhancing the environment for pedestrian traffic, more workers would have incentive to walk, windowshop, browse, as well as buy. The effect would be to potentially upgrade the retail shopping environment of the Central Business District for workers and residents.

Among the key functional issues that would have to be resolved before the Vehicle Free Zone were delineated is the relocation of bus routes currently using the three major streets that would be closed. On preliminary analysis, 12 routes would be affected. Unless provisions were made for bus travel within the Vehicle Free Zone, workers and shoppers boarding and unboarding in the downtown would be required to walk an additional 300-500 feet in order to get the bus at Kennedy Plaza. At present, many workers get off buses right at Turks Head Square and thus walk less than 200 feet to get to their place of work. In addition, many workers and shoppers (including many elderly) at present board and unboard buses at the Howard Building, which both offers protection against inclement weather and is immediately adjacent to the beginning of Westminster Mall.

As discussed under "Intermediate Traffic Redistribution," creation of the Vehicle Free Zone would require drivers and transit users to adjust their travel patterns through the downtown. It is expected that such adjustments could easily be made in the short run, and no significant long-term social impacts would occur. On the basis of the traffic flow analyses now being conducted by city departments and Interface: Providence,[*] downtown travel patterns will be required to change regardless of whether or not the Vehicle Free Zone is implemented, and much of the through-traffic presently using Dorrance Street will be directed circumferentially around the downtown core. It should be noted that any increases in vehicle speeds that would result from this strategy package are directly attributable to the computerized traffic signalization system (see separate discussion), and not to the Vehicle Free Zone itself. Similarly, any reduction in vehicle/vehicle and vehicle/pedestrian conflict in Memorial Square is attributable specifically to the redesign of this intersection regardless of whether the Vehicle Free Zone is created.

In summary, assuming that functional issues were resolved, the primary social impacts of the Vehicle Free Zone would be positive.

Economic impacts — The discussion of economic impacts of the proposed Vehicle Free Zone focuses upon two general areas:

- Economic impact upon city and state financial resources, in terms of capital and operating costs; and
- Economic impact upon the vitality and health of the downtown.

(Here the original report presented an analysis of the economic aspects of vehicle free zones in several U. S. cities, which is deleted here.)

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[*] Interface: Providence is a planning project of the Rhode Island School of Design.

As most malls or Vehicle Free Zones to date have been implemented for the purpose of increasing the economic vitality of the downtowns in which they are located, determination of the level of project expenditure has generally involved working within a given budgetary constraint to determine the amount of public investment that is required in order to generate a financial return. Again, as most of these projects have been undertaken in downtown retail areas, projected financial return has generally been measured chiefly in terms of changes in the levels of retail sales activity, quantitative and qualitative changes in property values and vacancy rates, and thereby, changes in sales and property tax receipts. In the case of the proposed Vehicle Free Zone, however, it is more difficult to define what constitutes a reasonable expenditure. First, the Vehicle Free Zone has been proposed not for the purpose of increasing downtown economic vitality; rather it is proposed primarily as a strategy for reducing carbon monoxide by reducing traffic congestion, with considerations of downtown economic enhancement secondary. In addition, as the primary land uses in the study area are office and financial, rather than retail, it is more difficult to define the expectations of the project in terms of anticipated financial return. Another limitation involved in developing a preliminary cost estimate for this Vehicle Free Zone strategy concerns the fact that by necessity project costs are a direct result of functional and design considerations that must be analyzed and incorporated into a particular plan.

In essence, the development of a reliable cost estimate for the Vehicle Free Zone Strategy is constrained without

- A further definition of expected return
- An identification of functional requirements (including the facilitating of deliveries and trash collections, installation of necessary utilities, provision for emergency vehicles, and definition of space/activity needs); and
- Identification of the level of amenity and enhancement to be incorporated into the physical design.

(Details of the cost estimate are deleted here.)

Table B-9 presents the total cost of implementing the Vehicle Free Zone strategy. This includes the cost of Vehicle Free Zone itself, the cost of reconstructing the Memorial Square intersection, and the cost of computerized traffic signalization in the downtown. As seen in Table IV-9, the total cost of this strategy option is $1.59 million. (See the sections on Alternatives No. 1 and 2 for an analysis of costs for these additional two items.)

Table B-9. TOTAL COST: VEHICLE FREE ZONE STRATEGY

Capital Costs	
• Vehicle Free Zone	$ 910,000
• Memorial Square Improvements (Phase I)	30,000
• Computerized Traffic Signalization	650,000
Total, Capital Costs	$1,590,000
Operating Costs	
• Vehicle Free Zone	$ 51,300
• Additional labor	10,500
Total, Annual Operating Costs	$ 61,800

The financing of a project of this magnitude presents considerable political and social obstacles, particularly in light of the fact that the State will be operating on an austerity budget. In terms of application of federal funds for this project, the City of Providence will be receiving $9.11 million in Community Development block grant funds in 1975; $8.645 million in 1976; and $8.216 million in 1977. These funds are for application toward capital projects and public services citywide. Under the U.S. Department of Housing and Urban Development procedural guidelines, the City of Providence was to have submitted an application for CD funds to HUD by April 15, 1975. This application was expected to include the submission of a 3-year program identifying the projects which will be undertaken. As discussed in the analysis of Legal and Administrative Issues, the Vehicle Free Zone proposed here is not at present included within the list of projects presently being planned by the City of Providence.

As funding from city, state, and federal sources presently appears limited, it may be necessary to use a combination of public/private funding to undertake the Vehicle Free Zone projects. A discussion of Special Assessment and Special District funding is also found in the analysis of Institutional impacts below.

In view of the limited data available on downtown Providence concerning such factors as employment trends, retail sales trends, property values, building rental and vacancy rates, and new construction and investment, it is not possible to adequately evaluate impacts of the proposed Vehicle Free Zone upon the general economic climate of the downtown. A further limitation concerns the fact that no economic or functional feasibility analyses have been conducted. It should also be noted that the proposed Vehicle Free Zone is not yet part of a comprehensive city effort to address the problems of the downtown. Thus, it cannot be assumed that supporting policies and actions on the part of the public and private sectors will necessarily accompany this strategy in a downtown revitalization effort.

For these reasons, it would be premature to do any detailed analysis at this time. It is noted, however, that a vehicle free zone or mall is traditionally associated with retail and specialty shops, and not with banks, office, and office-supporting services such as are now found in the area.

The effect of a vehicle free zone within this area could be to bring about a change in building use, particularly at street level, and a shift in location of some retail activity from the far end of Westminster Mall to locations closer to the office center at Turks Head Square. In addition, an increase in restaurant and other service establishments would be expected. Outside of the vehicle free zone itself, a major increase in sales activity at the lower end of Westminster Mall would be likely to result.

As an indication of public action to revitalize the downtown, the Vehicle Free Zone could serve as incentive for the investment of private capital. Assuming construction of the Vehicle Free Zone were to occur, additional employment would be generated in the construction industry. Such employment could partially alleviate the high unemployment rate in the city and state.

In summary, there would be difficulties in funding a project of the magnitude of the proposed Vehicle Free Zone. If such difficulties were overcome, the economic effects of this project upon the CBD would be generally positive, although it is likely that economic effects alone would be accomplished with more selective expenditure.[11]

Note that there are a myriad of issues identified here. The complexity of traffic redistribution measures is well illustrated by the foregoing example.

Institutional Impacts

General - Institutional considerations for the implementation of traffic flow improvement measures include the legal and administrative requirements of program approval and enforcement. Legal issues include the identification of legal authority necessary for implementation as well as any postimplementation legal problems which may arise. Administrative issues include the source of funding, identification of the necessary groups to be coordinated for implementation, and anticipation and resolution of community opposition for the proposed program.

With the exception of those measures such as parking restrictions and vehicle restricted areas which are overtly designed to prohibit or restrict the free movement of automobiles, most techniques to improve traffic flow are relatively easy to implement, because their benefits are usually apparent to the public.

Traffic Flow Improvements - Most cities have the legal authority and an existing administrative structure that is capable of approving, implementing and enforcing a traffic flow improvement program. It appears that in most cases the major obstacle to implementing traffic flow improvements is funding.

Federal funding for such programs is currently authorized through the Urban Area Traffic Operations Improvement Programs (Section 135, Title 23 of the United States Code). The purpose of this program is to reduce traffic congestion and to facilitate the flow of traffic in urban areas through implementation of improvements such as grade separation of intersections, widening of lanes, channelization of traffic, traffic control systems, and loading and unloading ramps. There is, however, significant competition among urban areas for limited available funds and as a result, not all worthy projects can be funded. Other sources of funds are municipal, county, and state agencies, but these vary among jurisdictions and cannot be described in this general guideline.

Traffic Restrictions - Measures such as parking restrictions and vehicle restricted zones designed to restrain the free movement of automobiles may be faced with opposition from automobile owners, local residents, and local merchants who anticipate that vehicle restraints will be harmful to their businesses. From the standpoint of institutional feasibility, these measures will be more difficult to implement than more politically acceptable measures to improve traffic flow.

Parking Restrictions - There are several important issues that must be addressed regarding the potential use of regulations and pricing policies for restricting parking for the purpose of air pollution control.[*]

First, it would be difficult to control all parking spaces, particularly already-existing space provided for employee parking by private firms and government agencies.

> "New space may be limited by zoning and building restrictions[+] as in the center of New York City, but if controls are imposed only on those having no access to private spaces, discrimination is introduced. The social and political consequences would have to be evaluated in each case. Second, public action to restrict the supply of space may afford excessive profits for parking operators by allowing increases in market-set rates.

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[*] The following discussion is based upon Reference 4 which in turn draws upon Lyle C. Fitch and Associates, Urban Transportation and Public Policy (San Francisco: Chandler Publishing Co., 1964), pp. 150 ff.

[+] In most metropolitan areas, it has been traditional practice -- in an attempt to secure more adequate off-street parking -- to require that a minimum number of parking spaces be provided in or adjacent to new buildings. A reversal of this policy, which has been achieved only with some difficulty in most jurisdictions, is bound to be disputatious and time-consuming, and in any event would have little overall effect from an air pollution point of view during at least another decade. Regulation of private property would be another possibility. However, there have been very few attempts, and none successful, to regulate the use private owners make of their property for private parking. Private owners, for example, may provide parking spaces, free of charge, for their employees and customers, although they may not run a public, for charge, parking service without appropriate land-use permits. Regulating private provision of parking, especially for employees on the premises, would be a substantial new intervention in the private use of land, and would take considerable time to introduce and implement. No cities could be realistically expected to have an effective parking regulation of this type by 1977 (the present legal deadline for attainment of CO air quality standards).

> Capturing these excess profits for public purposes would be politically difficult in many cases (e.g., where parking lots in garages are operated predominantly by large firms). This suggests that taxes are a much more acceptable means of raising parking rates. Third, a policy of regulating parking space would encounter the staunch opposition of all those who would be brought under control, a not inconsiderable force. And there would always be pressure for special arrangements, protection of "grandfather rights" and so on. Again, this suggests the desirability of the pricing approach. No parking program of regulation would be anywhere near 100 percent effective, while a comprehensive parking space tax might reach 85-90 percent of all off-street spaces.
>
> Imposing parking charges would be subject to some of the same institutional problems indicated above. However, it appears unquestionable that municipal corporations can either regulate prices for parking (as in the case of a public service or utility), or impose taxes upon parking which would have the effect of raising parking prices. Raising parking prices would be politically difficult, and would certainly involve confrontations between those raising charges and those whose interests are directly affected (e.g., retailers and office building owners).
>
> Generally speaking, parking pricing appears preferable to parking regulation, in that the former can be differentiated according to impact (e.g., to discourage parking during peak hours but not for business purposes before and after peak hours). It is doubtful that the same ends could be gained and the same degree of control achieved (e.g., encouraging midday use) by enforceable regulatory restrictions. Furthermore, taxes appear to be a more attractive because they supply municipal revenues which are always badly needed."[4]

Vehicle Redistribution - Vehicle redistribution away from hot spots is accomplished by restricting the use of motor vehicles by direct, enforced, administrative action. Correspondingly, they are dependent "...upon police powers (or other enforcement) for their effectiveness; and this would appear to be a major institutional problem. From the legal standpoint, it appears that all municipalities have the authority to regulate road use, and in the event that existing authority were in some way inadequate, it could probably be obtained. Important legal problems, however, could well arise from court challenges by abutting property owners, who might claim that the value of their property had been reduced by limiting or preventing vehicular access without due process of law. Conceivably, some municipalities might have to make compensatory payment for such cases."[4]

The following discussion presents an example analysis of the institutional issues that were identified for the Vehicle-Free Zone strategy that was proposed as part of the previously discussed Rhode Island TCP. The discussion is taken substantially from Reference 11.

Institutional Issues Pertaining to a Vehicle Free Zone - There are a a number of significant legal and administrative issues that would have to be resolved before the Vehicle Free Zone strategy could be implemented. The most important of these issues are:

1. The need for extensive cooperation between State and City governments and among governmental actors, the business community, and the general public.
2. Coordination of transportation control plan strategies such as the Vehicle Free Zone with traffic flow and urban design proposals now being developed by Providence city planners and the Interface: Providence team.
3. Resolutior of funding issues including use of special assessment or special district funding mechanisms.
4. Obtaining the necessary legal authority, in the form of state enabling legislation and city ordinances, in order to close streets and undertake the necessary surface and subsurface construction.

Perhaps the greatest problem involved in the implementation of the Vehicle Free Zone strategy is the need for extensive cooperation and coordination between City and State government agencies, including the Governor's office, the Rhode Island Department of Public Health, and the Rhode Island Department of Transportation (both of whom are key agencies involved in formulation of the transportation control plan), and city agencies including the Providence Department of Planning and Development, the Traffic Engineering Department, and the Office of the Mayor. In order to both get the Vehicle Free Zone project underway and to handle many functional, administrative, and design details that would have to be resolved in pre-construction phases, it will be necessary for the city to take the lead in project promotion and development. The cooperation of the private sector will be a key factor in this effort. Among the many groups from whom participation would be required and cooperation essential are the Greater Providence Chamber of Commerce, the Chamber's offshot agency, the INTOWN Association; the Interface: Providence planning and design team; the financial community centered in Turks Head Square; the local merchant and business community; and the general public.

To assure the cooperation of all of these actors, it would be necessary to demonstrate the feasibility of the Vehicle Free Zone on three levels: economic, functional, and political. Economic feasibility involves demonstrating what effect the project could have upon the economic strength of the downtown. This includes increasing or stabilizing business and sales, effect on construction, private investment, and rehabilitation, and effect on employment. It also includes the impact of the project on property values and on tax receipts, as well as the impact on local expenditure patterns (i.e., a larger share of the city financial resources to downtown may mean a smaller share for local neighborhoods in competition for scarce funds). Functional feasibility means resolving the issues of merchandise delivery and pickup, traffic flow, accessibility, and parking, as well as the public service and utility issues such as rubbish collecting, emergency vehicle access, and underground improvements to sewer, water, electricity, and gas lines. Political feasibility means, in short, demonstrating the leadership that is required in order to coordinate the diverse interests of the private and public actors involved, and to bring these interests into harmony in a conceptual design.

As can be seen from the cost analysis of the Vehicle Free Zone (contained elsewhere in this section), the base estimated cost of the proposed Vehicle Free Zone is $910,000. This estimate is independent of the cost of redesigning Memorial Square and of installing a computerized traffic signal system in the CBD. If these two projects were undertaken as well, the total funding required in order to implement this strategy would be $1.59 million. Even if federal Community Development (CD) funds were used to finance part of the cost of implementation, other funding sources would have to be pursued in view of the limited availability of City and State funding. One funding assistance mechanism used by cities which have undertaken mall projects in the past is to levy a special assessment (or benefit assessment) upon enterprises within the boundaries of a specially formed Special Assessment District. The rationale for this approach is that such enterprises would normally be expected to benefit from a mall project, and thus should be expected to help defray the cost of mall construction and maintenance. To apply this approach to the proposed Vehicle Free Zone would require additional state enabling legislation empowering municipalities to create special districts with assessment levying powers. A major limitation on applying this approach to the mall proposed here is due to the fact that office enterprises form the predominant land use in the Vehicle Free Zone area. If the predominant land use were retail, then benefit would accrue to district enterprises in the form of increased sales. The benefit accruing to office enterprises are more aesthetically than financially rewarding. For this reason, there would be considerable opposition to applying the special assessment approach to the proposed Vehicle Free Zone.

The final legal and administrative issue that would have to be resolved pertains to obtaining the necessary legal authority to undertake the project. Although City and State legislation were required to implement the existing Westminster Mall, this legislation may be limited in geographic scope to pertain only to the existing mall area.

The example given, that of a Vehicle Free Zone, is particularly complex. It illustrates the kinds of issues that must be addressed, and shows how these issues must be weighed by the decision-maker.

Macroscale Travel Effects

One concern that has been repeatedly expressed in the literature (see Reference 4, for example) is that local improvements to traffic conditions will encourage more trips. That is, the microscale increases in speed and flow will encourage people to reroute their trips to take advantage of the improvements, thus altering macroscale travel patterns and causing the air quality benefits of the control measures to be less than anticipated.

This type of macroscale redistribution may indeed occur and should be expected and planned for, if appropriate. In the case of a highly localized improvement that affects only a small portion of the travel network, an engineer or planner familiar with the area should be able to roughly predict any redistribution that would occur. Where larger CO control areas are to involve extensive flow improvements, it would probably require a planning study to evaluate the effect. Such a study would determine which trips would be diverted from alternative routes to use some or all of the streets whose conditions are being improved. If substantive unintended redistribution is a possibility, it should be considered during the basic planning of the CO control measures. The Springfield, Mass., TCP, discussed earlier, required a special origin-destination survey in order to identify and plan for this type of redistribution.

In some cases it may be found that traffic flow improvements will encourage so much additional travel through an area that CO control is stymied. In that case, alternatives must be examined.

One alternative is to use deliberate redistribution to force traffic away from the "hot spots." A vehicle free zone achieves such a deliberate redistribution while not increasing macroscale traffic capacity of an area.

Another alternative is to expand the traffic flow improvement study area and determine whether simultaneous improvements on parallel routes would prevent or reduce the macroscale redistribution.

The third alternative is travel restraints. Overt restriction of automobile use has been discussed in connection with various TCP's, city planning concepts, and in the context of minimizing energy consumption. Such restraints include:

- Very large vehicle exclusion zones, such as vehicle free zones for entire downtown areas.
- Parking restrictions, road tolls, increased prices for parking, or other economic disincentives to travel.
- Policies to allow vehicles to enter certain areas only during particular times of day.

These types of measures are not very "popular," because they involve substantial perceived or actual negative impacts. Because such restraints are politically very difficult to implement, they will not be treated in detail here.* Nonetheless such measures represent an option that should be considered and that may be necessary in some locations.

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*The interested reader is referred to the extensive literature on experience in other countries with such restraints. In particular, the vehicle restrictions in Gothenburg, Sweden, have been described in American technical literature.[9,16]

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APPENDIX C

LOCATION SKETCHES

Following are the sketches that show operational and physical characteristics for those locations in Waltham, Massachusetts, that were analyzed with the second-step screening (verification) procedures.

Location	Page
SIGNALIZED	
Main Street at Warren Street	C-4
Main Street at Gore Street	C-5
Main Street at Linden Street	C-6
Main Street at Newton Street	C-7
Main Street at Appleton Street	C-8
Main Street at Elm and Church Streets	C-9
Main Street at Lexington Street	C-10
Main Street at Moody Street	C-11
Main Street at Bacon Street	C-12
Main Street at Prospect and Hammond Streets	C-13
Main Street at Weston Street	C-14
Weston Street at Eddy and Cabot Streets	C-15
Lexington Street at School Street	C-16

Location	Page
Lexington Street at Trapelo Road	C-17
Lexington Street at Bacon Street and Totten Pond Road	C-18
Moody Street at Maple and High Streets	C-19
Moody Street at Carter and Felton Streets	C-20
Bacon Street at School Street	C-21
Trapelo Road at Smith Street	C-22
Beaver Street at Waverly Oaks Road	C-23
Newton Street at River Street	C-24
South Street at Vernon Street	C-25
Prospect Street at Highlands and Felton Streets	C-26
Maple Street at Adams Street	C-27
High Street at Lowell Street	C-28
High Street at Newton Street	C-29
Trapelo Road at Waverly Oaks Road	C-30

NONSIGNALIZED INTERSECTIONS

Trapelo Road at Forest Street	C-31
Beaver Street at Forest Street	C-32
Moody Street at Crescent and Pine Streets	C-33
Moody Street at Crescent and Derby Streets	C-34
Lyman Street at Church Street	C-35
Crescent Street at Prospect and Maple Streets	C-36
Weston Street at South Street	C-37

Location Page

UNINTERRUPTED FLOW LOCATIONS

Trapelo Road C-38

Weston Street C-39

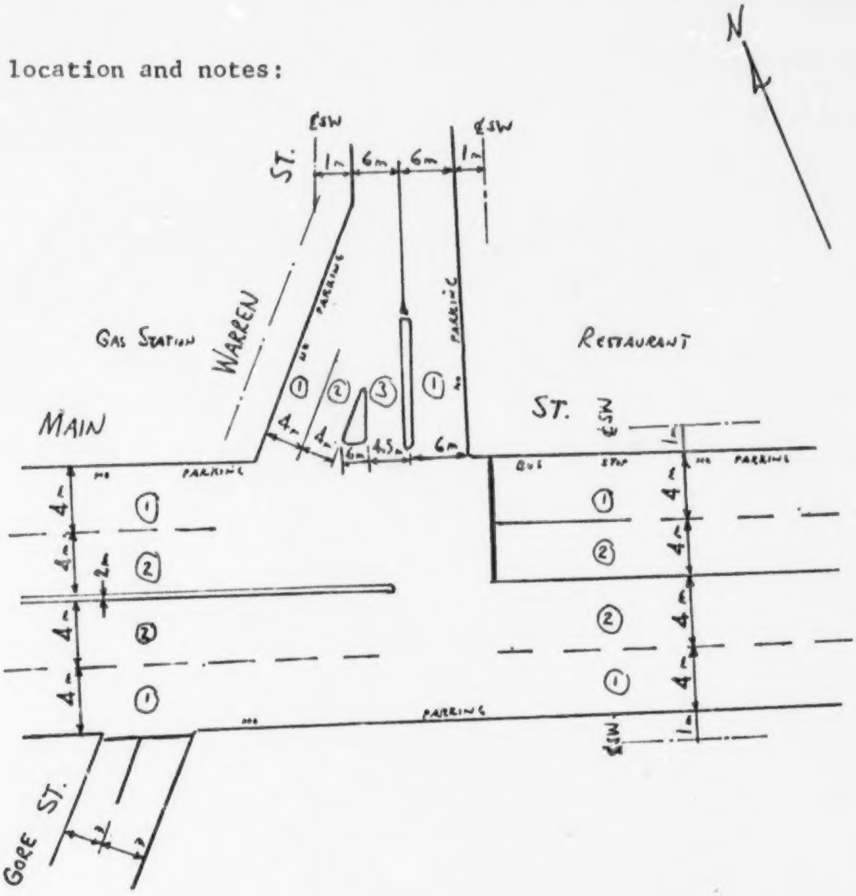
Route 128 C-40

HOT SPOT VERIFICATION SUMMARY

City/Town: WALTHAM MA. By: TPM

Location: MAIN ST. @ WARREN ST. Date: 9/26/75

Sketch of location and notes:


N
℄SW
℄SW
ST.
1m
6m
6m
1m
WARREN
NO PARKING
PARKING
NO
GAS STATION
RESTAURANT
①
②
③
①
4m
4m
6m
4.5m
6m
MAIN
ST.
℄SW
1m
NO PARKING
BUS STOP
NO PARKING
4m
4m
2m
4m
4m
①
②
②
①
①
②
②
①
4m
4m
4m
4m
NO PARKING
1m
℄SW
GORE ST.

NOTES:

1) NO PARKING WITHIN INTERSECTION

2) RECEPTORS ARE ℄ SIDEWALK

3) NO PEDESTRIAN INTERFERENCE

4) LAND USE IS MIXED RESIDENTIAL/COMMERCIAL, MODERATE DENSITY
EST. DEPARTURE CRUISE SPEED OF 30 mph.

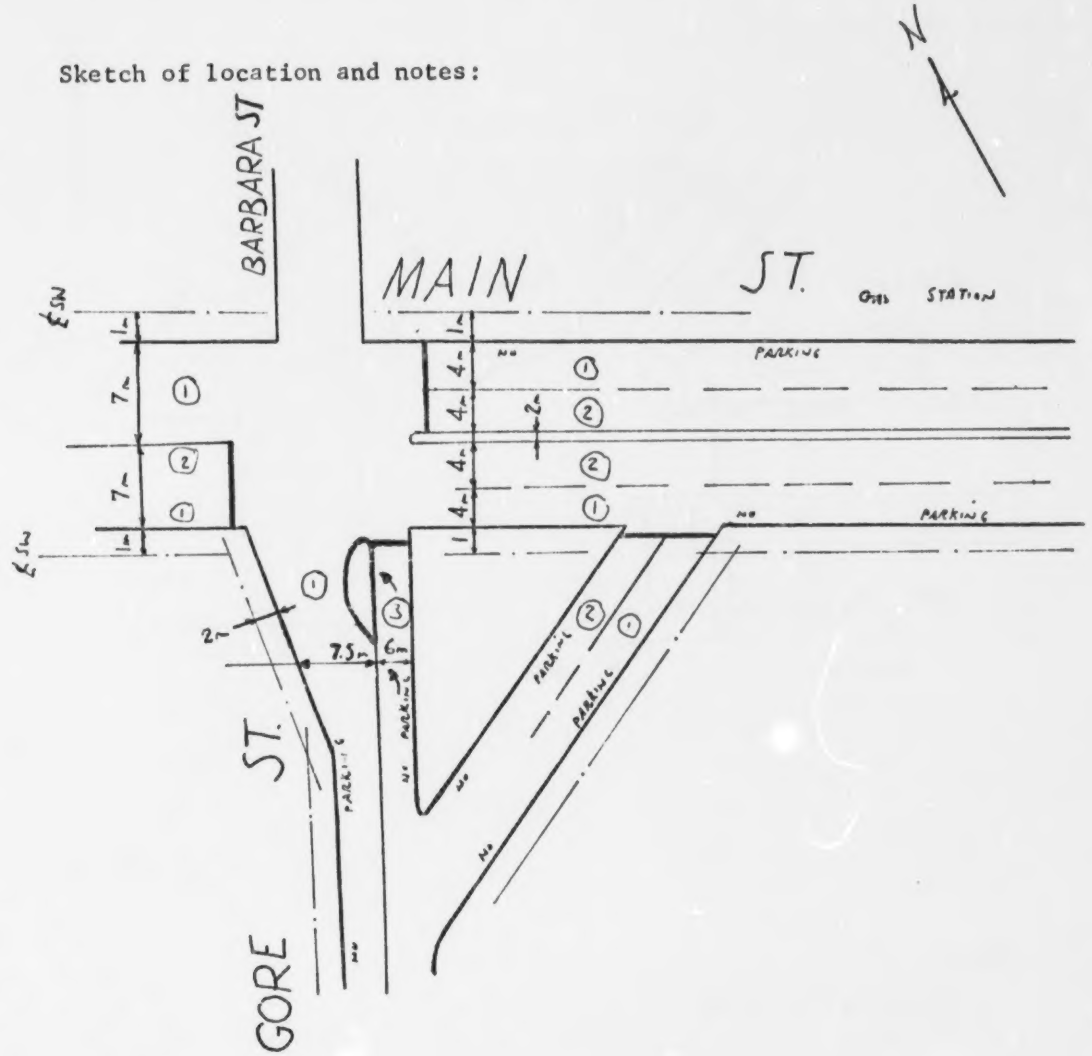
5) SIGNAL CONTROL

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma. By: TPM

Location: Main St. @ Gore St. Date: 26 Sep '75

Sketch of location and notes:


N
BARBARA ST
MAIN ST.
GAS STATION
NO PARKING
NO PARKING
℄ SW
℄ SW
1m
7m
7m
1m
1m
4m
4m
4m
4m
1m
2m
2m
7.5m
6m
①
②
③
GORE ST.
PARKING
NO PARKING
NO PARKING
NO PARKING

Notes:

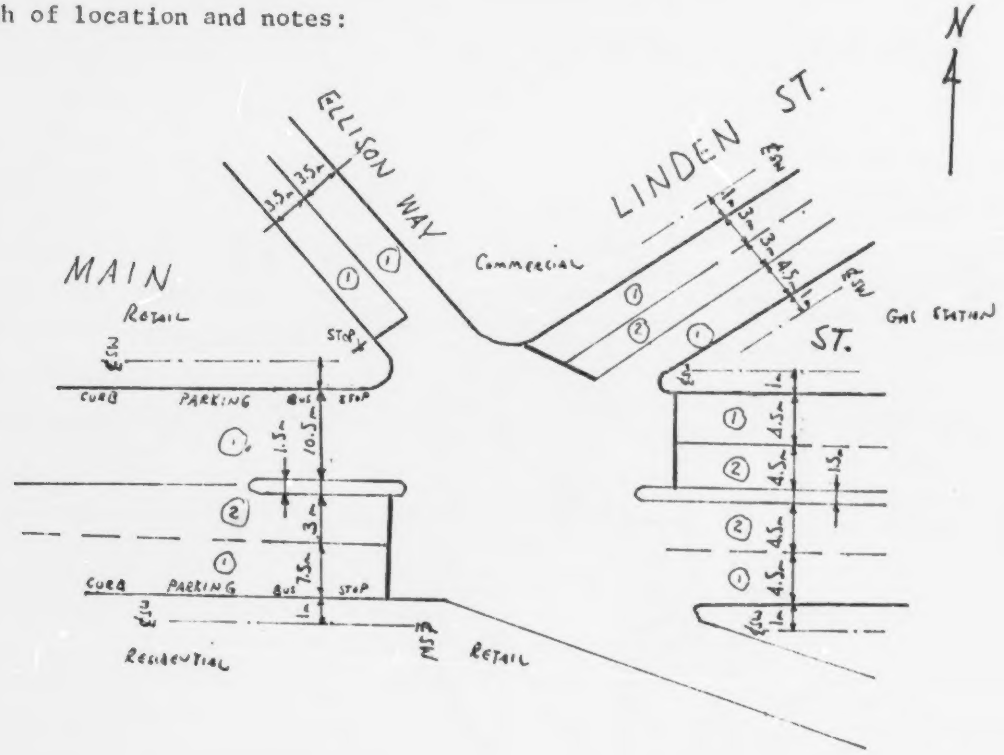
1) Parking as shown
2) Receptors @ ℄ Sidewalk
3) No pedestrian interference
4) Est. cruise speed is 30mph
5) Main St. E/B approach operates as two lane
6) Traffic signal control

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma By: TPM

Location: Main St. @ Linden St & Ellison Wy. Date: 9/26/75

Sketch of location and notes:


N
ELLISON WAY
LINDEN ST.
MAIN
ST.
Retail
Commercial
Gas Station
Residential
Retail
Curb
Parking
Bus Stop
Curb
Parking
Bus Stop
Stop
ESW
ESW
ESW
WSW
ESW
ESW
3.5m
3.5m
1m
3m
3m
4.5m
1m
10.5m
1.5m
3m
7.5m
1m
1m
4.5m
4.5m
1.5m
4.5m
4.5m
1m
3
3
3
①
②

Notes:

1) Parking as indicated

2) Recepetors are ℄ sidewalks

3) No pedestrian interference

4) Land use is mixed residential/commercial, moderate density
Est. departure cruise speed is 30 mph

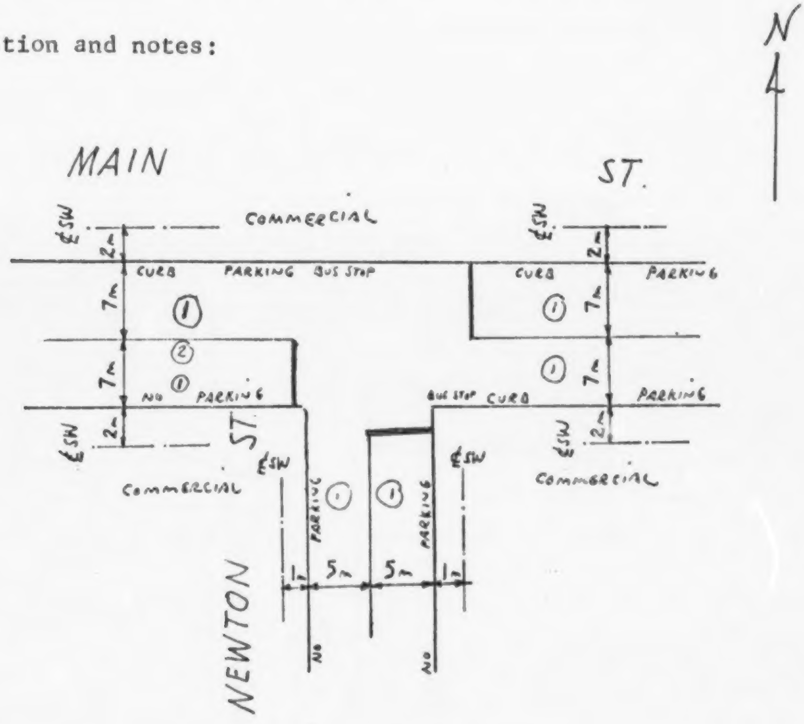
5) Traffic signal controls

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma By: TPM

Location: Main St. @ Newton St. Date: 26 Sep 75

Sketch of location and notes:


N
MAIN ST.
NEWTON ST.
COMMERCIAL
COMMERCIAL
COMMERCIAL
℄SW
℄SW
℄SW
℄SW
℄SW
℄SW
2m
7m
7m
2m
2m
7m
7m
2m
CURB
PARKING
BUS STOP
CURB
PARKING
NO PARKING
BUS STOP
CURB
PARKING
PARKING
PARKING
NO
NO
①
②
①
①
①
①
①
1m
5m
5m
1m

Notes:

1.) Parking as indicated

2) Receptors are ℄ sidewalk

3) Insignificant pedestrian activity during peak hour

4) Est. departure cruise speed is 30 mph

5) Eastbound approach of Main Street is two lanes

6) Traffic signal controls

HOT SPOT VERIFICATION SUMMARY

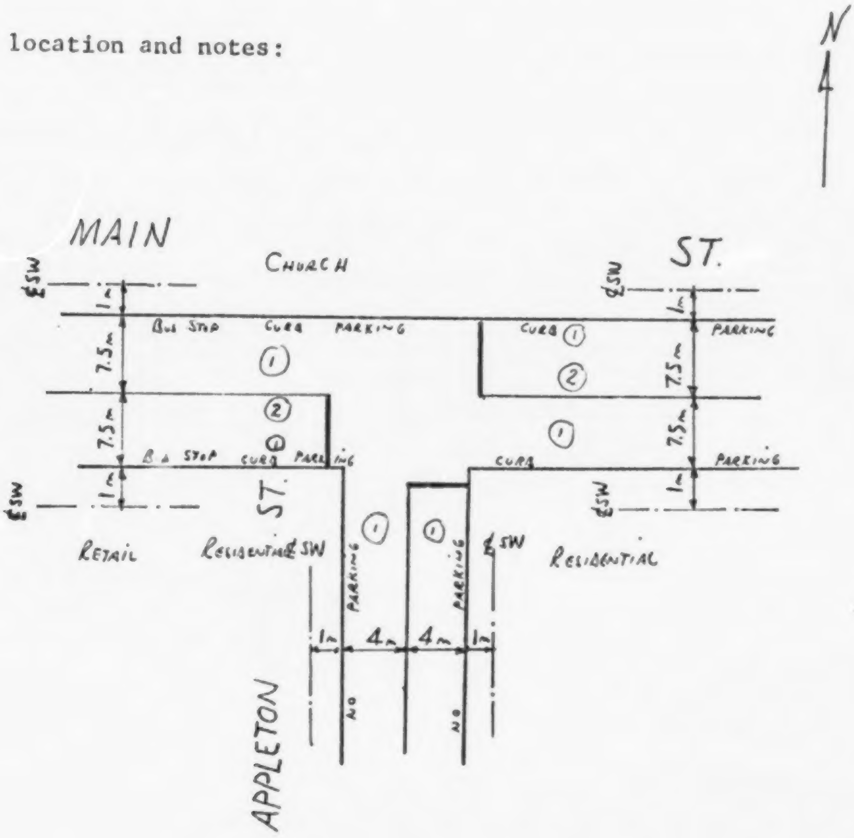
City/Town: Waltham, Ma.

By: TPM

Location: Main St. @ Appleton St.

Date: 26 Sep 75

Sketch of location and notes:


N
MAIN ST.
CHURCH
℄SW
1m
7.5m
7.5m
1m
Bus Stop
Curb
Parking
Curb
①
②
①
②
①
B s Stop
Curb
Parking
Curb
Parking
Parking
ST.
Retail
Residential
℄SW
①
①
Parking
Parking
℄SW
Residential
1m
4m
4m
1m
NO
NO
APPLETON

Notes:

1) Parking as shown

2) Receptors @ ℄ sidewalk

3) Insignificant pedestrian interference during peak hours

4) Est. departure cruise speed is 20 mph

5) Main St. operates with 2 lanes in each direction

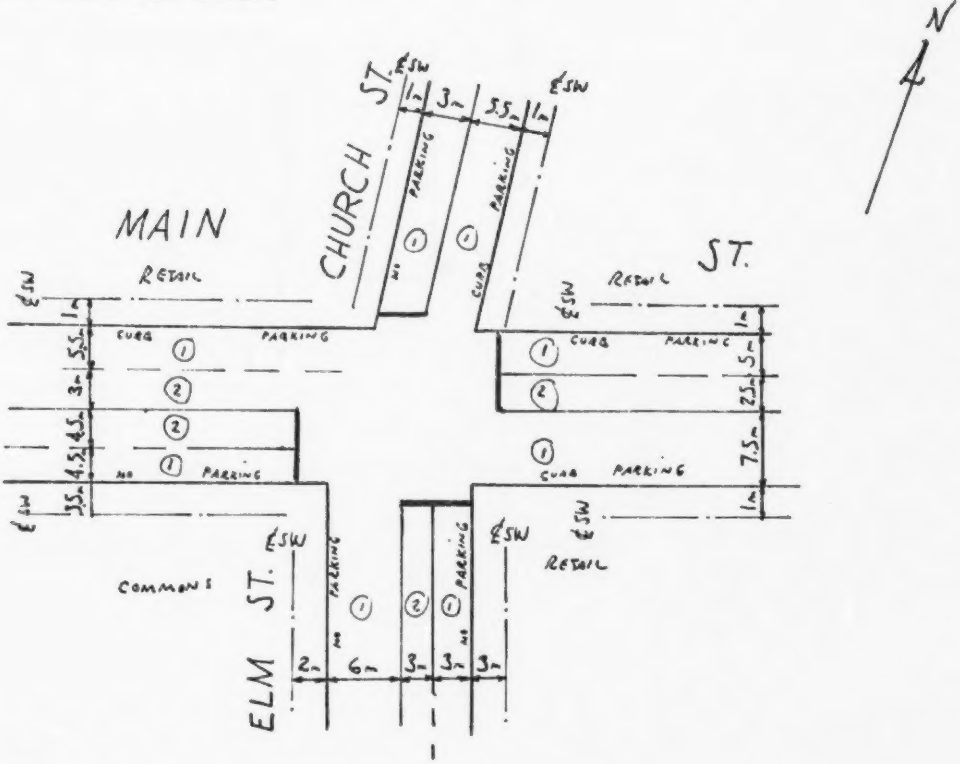
6) Traffic Signal Control

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma. By: TPM

Location: Main St. @ Elm & Church Sts. Date: 26 Sep '75

Sketch of location and notes:


N
CHURCH ST.
℄SW
1m
3m
5.5m
1m
℄SW
NO PARKING
CURB PARKING
MAIN ST.
RETAIL
℄SW
1m
5.5m
3m
4.5m
4.5m
3.5m
CURB PARKING
NO PARKING
①
②
②
①
CURB PARKING
1m
5m
2.5m
7.5m
1m
COMMONS
ELM ST.
℄SW
NO PARKING
2m
6m
3m
3m
3m
RETAIL

Notes:

1) Parking as shown

2) Receptors at ℄ sidewalk

3) Insignificant pedestrian interference during peak hours

4) Est. departure cruise speed is 15 mph

5) Free right turn from Main St. E/B. Lane blocked by through vehicles 20% of time

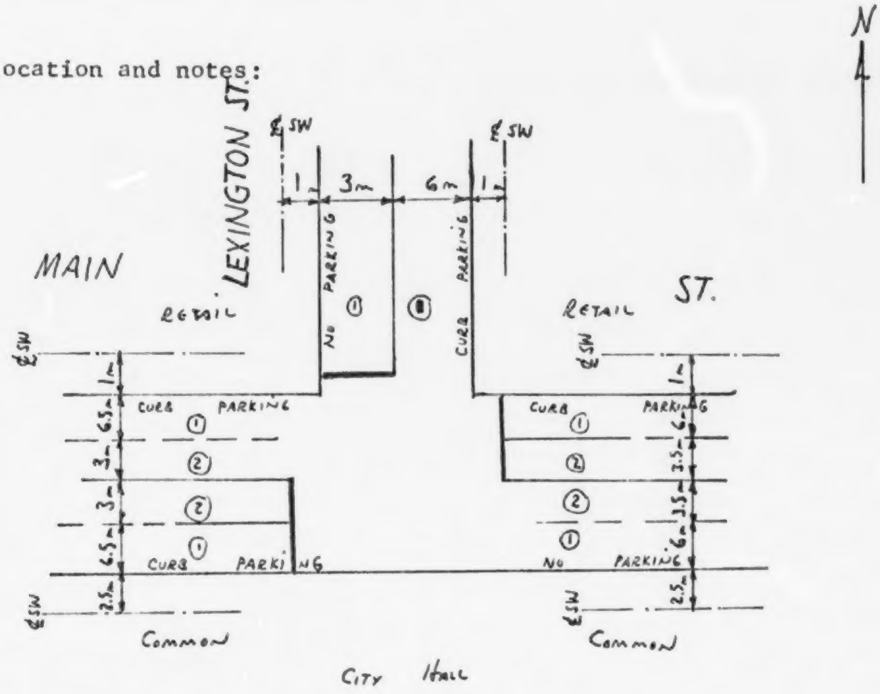
6) Traffic signal controls

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma. By: TPM

Location: Main St. @ Lexington St. Date: 26 Sep 75

Sketch of location and notes:


N
LEXINGTON ST.
MAIN
ST.
℄ SW
1m
3m
6m
1m
No Parking
Curb Parking
①
②
Retail
1m
6.5m
3m
2.5m
3.5m
6m
Curb Parking
No Parking
Common
City Hall

Notes:

1) Parking as shown

2) Receptors are ℄ sidewalk

3) No significant pedestrian activity during peak hours

4) Est. departure cruise speed is 15 mph

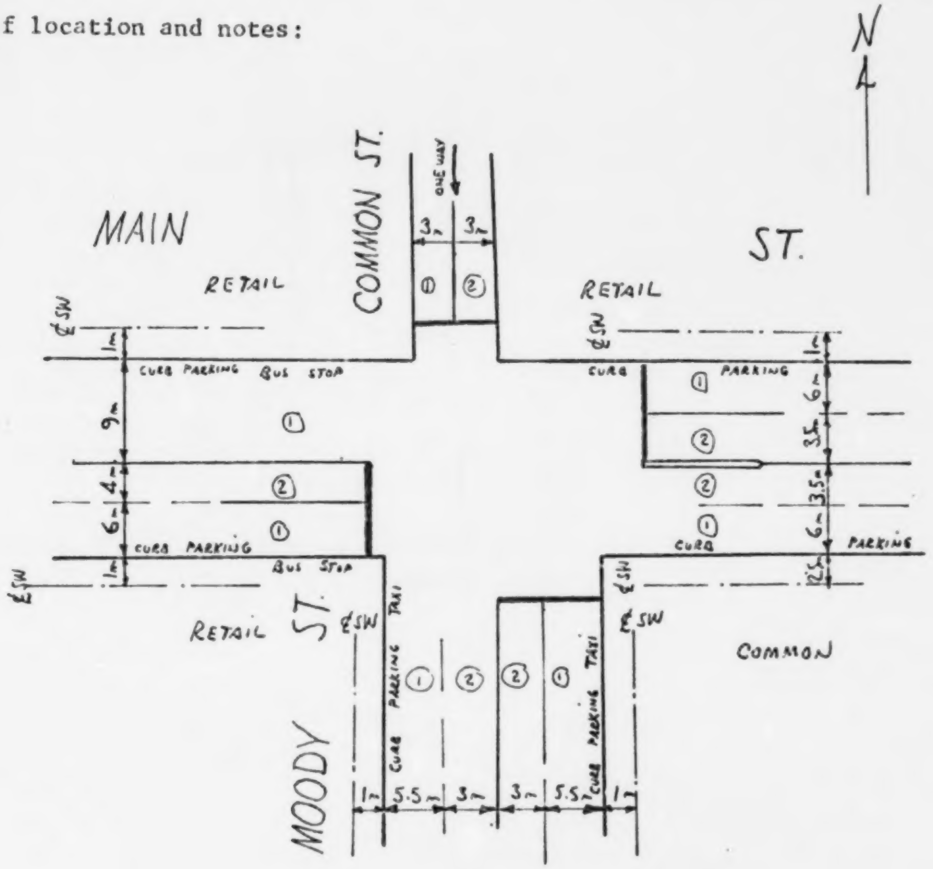
5) Traffic signal controls

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma. By: TPM

Location: Main St @ Moody St. Date: 26 Sep 75

Sketch of location and notes:


N
MAIN
COMMON ST.
ONE WAY
3m
3m
①
②
ST.
RETAIL
RETAIL
℄ SW
℄ SW
1m
CURB PARKING BUS STOP
CURB
PARKING
1m
9m
6m
①
①
3.5m
②
②
②
3.5m
4m
6m
①
①
6m
CURB PARKING
CURB
PARKING
1m
BUS STOP
1.5m
℄ SW
RETAIL
ST.
℄ SW
TAXI
℄ SW
COMMON
CURB PARKING
①
②
②
①
CURB PARKING TAXI
MOODY
1m
5.5m
3m
3m
5.5m
1m

Notes:

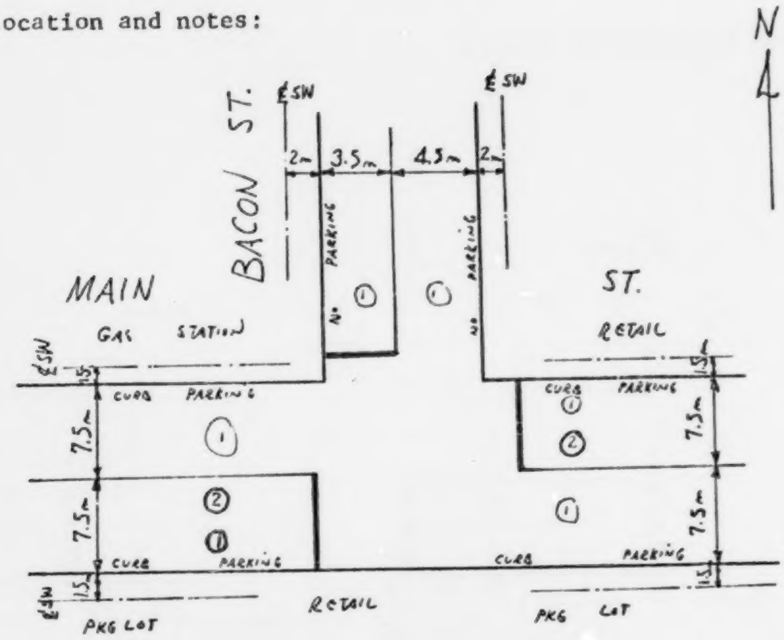
1) Parking as shown
2) Receptors at ℄ sidewalk
3) Insignificant pedestrian interference during peak hours
4) Est. departure cruise speed is 15 mph
5) Traffic signal controls

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma. By: TPM

Location: Main St. @ Bacon St. Date: 26 Sep 75

Sketch of location and notes:


N
BACON ST.
℄ SW
℄ SW
2m
3.5m
4.5m
2m
PARKING
NO
PARKING
NO
①
①
MAIN
ST.
GAS STATION
RETAIL
℄ SW
1.5
CURB
PARKING
7.5m
①
7.5m
②
①
CURB
PARKING
1.5
℄ SW
PKG LOT
RETAIL
CURB
PARKING
1.5
①
②
7.5m
①
7.5m
CURB
PARKING
1.5
PKG LOT

Notes:

1) Parking as shown

2) Receptors at ℄ sidewalk

3) Insignificant pedestrian interference during peak hours

4) Est. departure cruise speed is 20 mph

5) Main St. approaches operate as two lanes

6) Traffic signal controls

HOT SPOT VERIFICATION SUMMARY

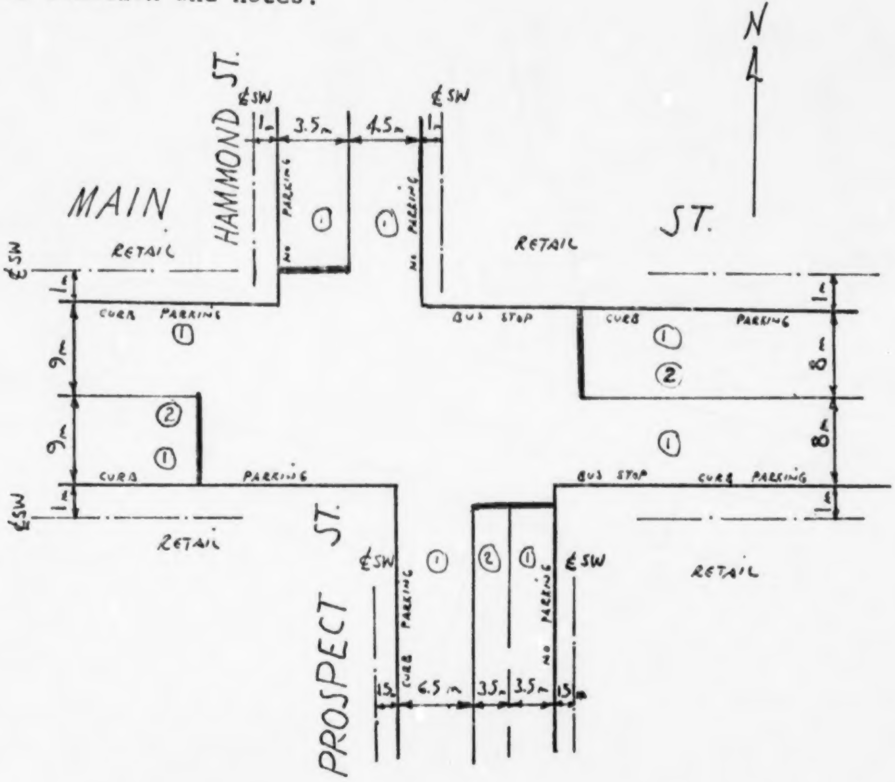
City/Town: Waltham, Ma.

By: TPM

Location: Main St. @ Prospect St. & Hammond St.

Date: 26 Sep '75

Sketch of location and notes:


N
HAMMOND ST.
MAIN
ST.
PROSPECT ST.
℄SW
℄SW
℄SW
℄SW
℄SW
℄SW
1m
3.5m
4.5m
1m
PARKING
NO PARKING
RETAIL
RETAIL
RETAIL
RETAIL
1m
9m
9m
1m
1m
8m
8m
1m
CURB PARKING
CURB PARKING
BUS STOP
CURB PARKING
BUS STOP
CURB PARKING
CURB PARKING
NO PARKING
1.5
6.5m
3.5m
3.5m
1.5
①
②

Notes:

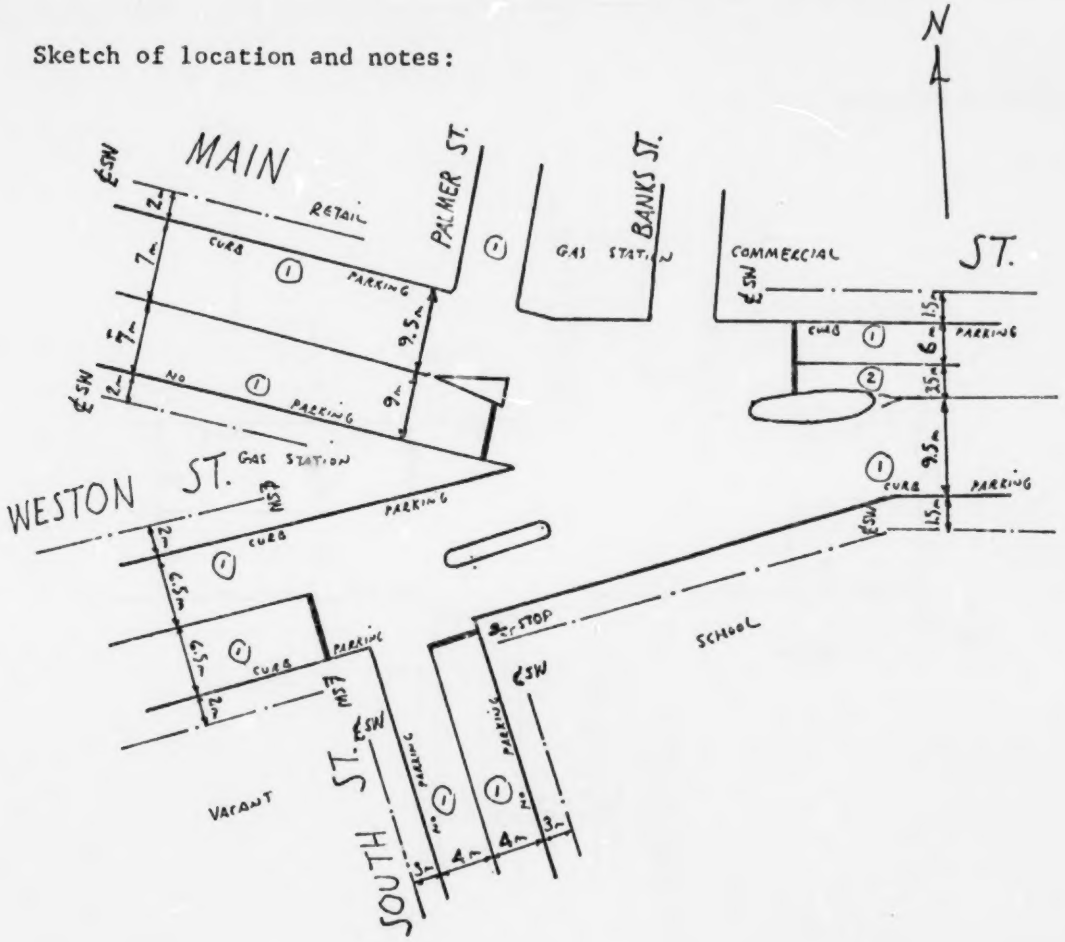
1) Parking as shown
2) Receptors at ℄ sidewalk
3) Insignificant pedestrian interference
4) Est. cruise speed is 20mph
5) Main St. approaches operate as two lane
6) Traffic signal controls

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma By: TPM

Location: Main St. @ Weston St. & South St. Date: 22 Sep '75

Sketch of location and notes:


N
MAIN
ST.
PALMER ST.
BANKS ST.
RETAIL
CURB
PARKING
NO PARKING
GAS STATION
COMMERCIAL
WESTON ST.
SOUTH ST.
VACANT
SCHOOL
STOP
℄SW
2m
7m
9.5m
9m
1.5m
6m
3.5m
6.5m
3m
4m
①
②

Notes:

1) Parking as shown

2) Receptors at ℄ sidewalk

3) Insignificant pedestrian interference during peak hours

4) South Street controlled by flashing red

5) Mixed commercial/residential; Est. departure speeds - 25 mph on South St; 30 mph on Main and Weston Sts.

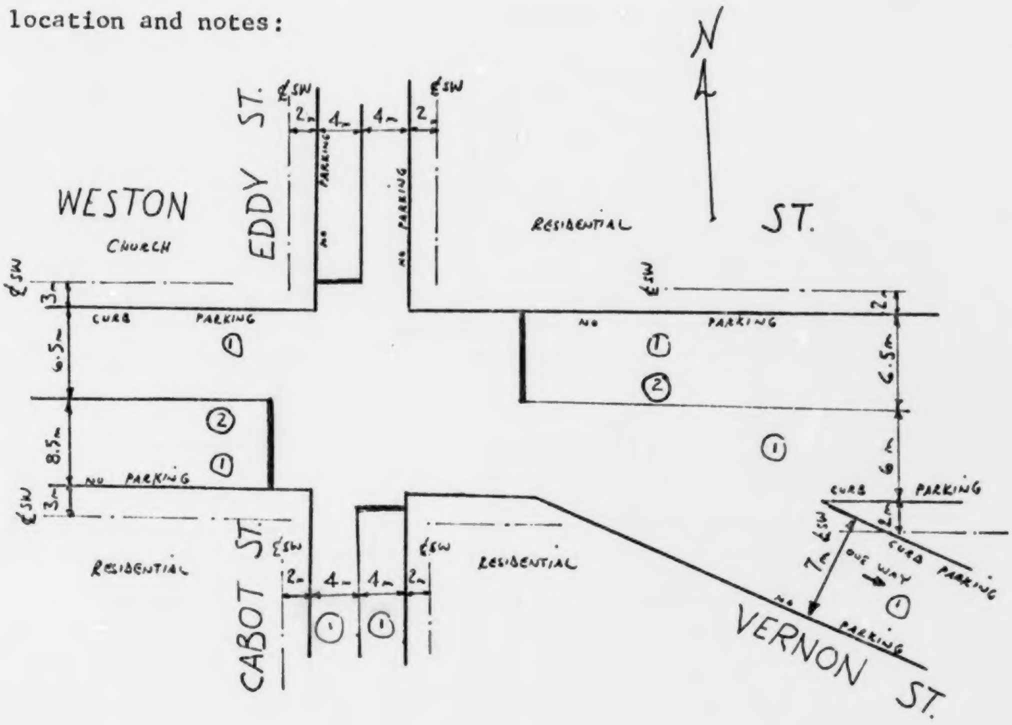
6) Traffic signals control all except South St.

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma. By: TPM

Location: Weston St. @ Cabot St., Eddy St, and Vernon St. Date: 26 Sep '75

Sketch of location and notes:


N
EDDY ST.
℄SW
℄SW
2m
4m
4m
2m
No parking
No parking
WESTON
ST.
CHURCH
RESIDENTIAL
℄SW
3m
Curb
Parking
①
6.5m
②
①
8.5m
No parking
3m
℄SW
No
Parking
①
②
2m
6.5m
①
6m
Curb
Parking
2m
℄SW
7m
One way
Curb
Parking
①
No
Parking
VERNON ST.
CABOT ST.
℄SW
℄SW
2m
4m
4m
2m
① ①
RESIDENTIAL
RESIDENTIAL

Notes:

1) Parking as shown

2) Receptors at ℄ sidewalk

3) No pedestrian interference

4) Est. departure cruise speed is 30mph

5) Weston St. approaches with two lanes

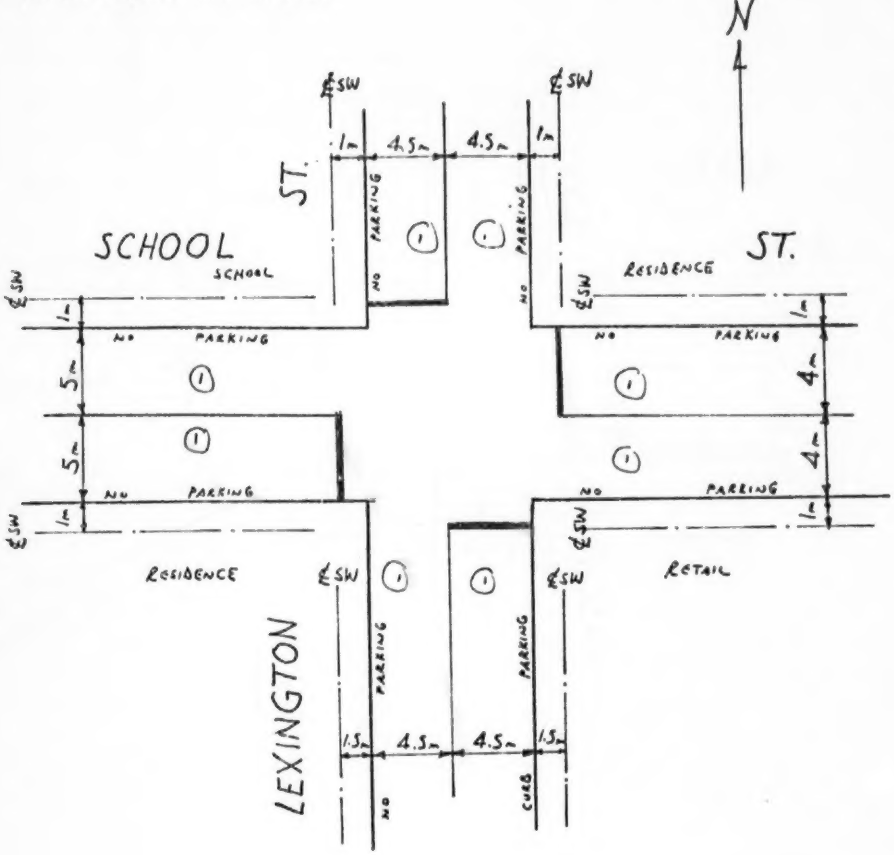
6) Traffic signal controls

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma By: TPM

Location: Lexington St. @ School St. Date: 26 Sep '75

Sketch of location and notes:



N
℄SW
1m
4.5m
4.5m
1m
SCHOOL
ST.
School
Residence
NO PARKING
NO PARKING
5m
5m
4m
4m
1m
①
Residence
Retail
LEXINGTON
1.5m
4.5m
4.5m
1.5m
NO PARKING
CURB PARKING

Notes:

1) Parking as shown

2) Receptors at ℄ sidewalk

3) Insignificant pedestrian interference during peak hours

4) Est. departure cruise speed is 15 mph

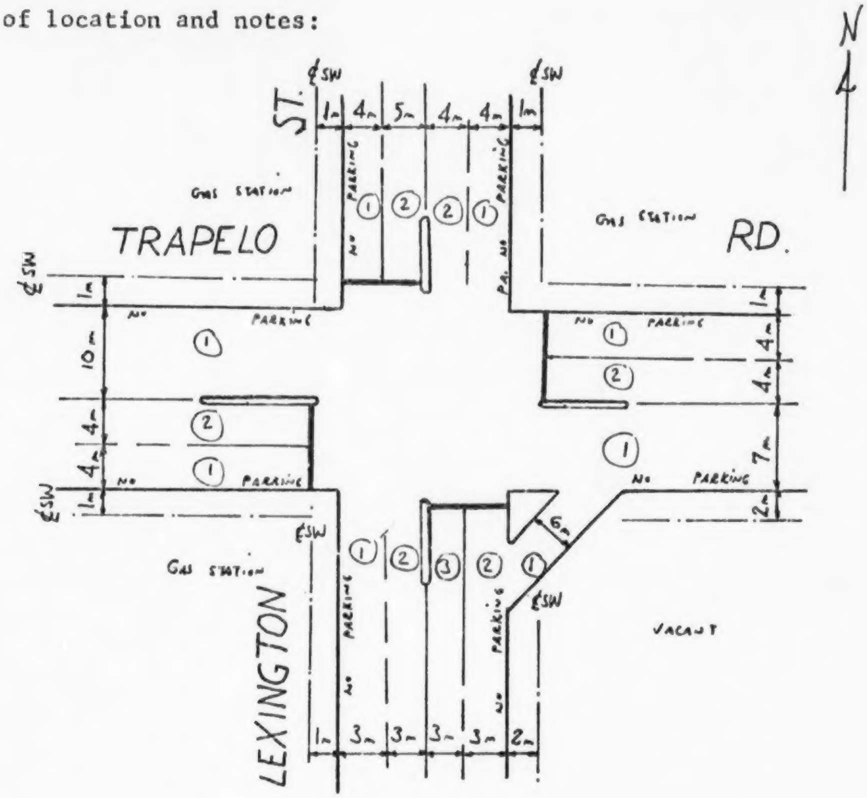
5) Traffic signal controls

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma. By: TPM

Location: Trapelo Rd. @ Lexington St. Date: 26 Sep'75

Sketch of location and notes:


N
℄SW
ST.
1m
4m
5m
4m
4m
1m
GAS STATION
TRAPELO
RD.
NO PARKING
①
②
③
10m
4m
4m
1m
7m
2m
6m
GAS STATION
VACANT
LEXINGTON
1m
3m
3m
3m
3m
2m

Notes:

1) Parking as shown

2) Receptors at ℄ sidewalk

3) No pedestrian interference

4) Est. cruise speed is 30 mph

5) Free right turn from Lexington St N/B

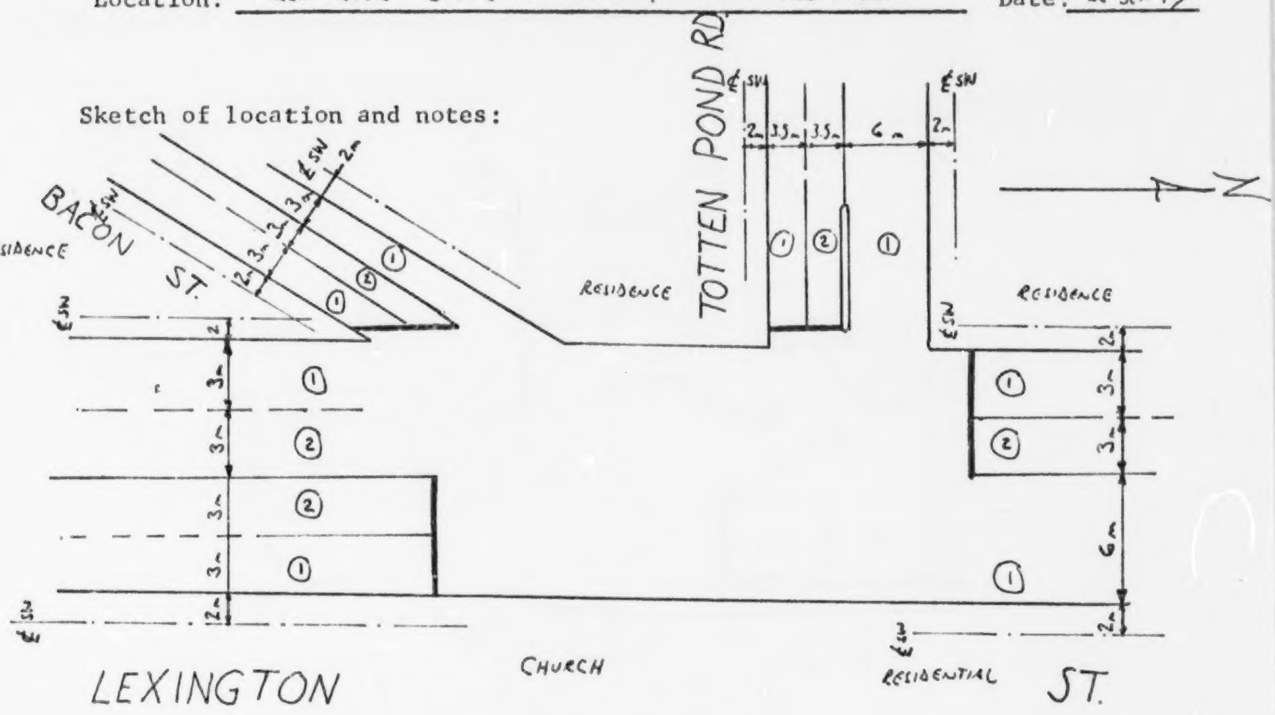
6) Traffic signal controls

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma. By: TPM

Location: Lexington St. @ Bacon St. & Totten Pond Rd. Date: 26 Sep '75

Sketch of location and notes:



BACON ST.
RESIDENCE
TOTTEN POND RD.
RESIDENCE
RESIDENCE
N
℄ SW
2m
3.5m
3.5m
6m
3m
① ② ①
LEXINGTON
CHURCH
RESIDENTIAL
ST.

Notes:

1) Parking as shown

2) Receptors at ℄ sidewalk

3) No pedestrian interference

4) Est. departure cruise speed is 30mph

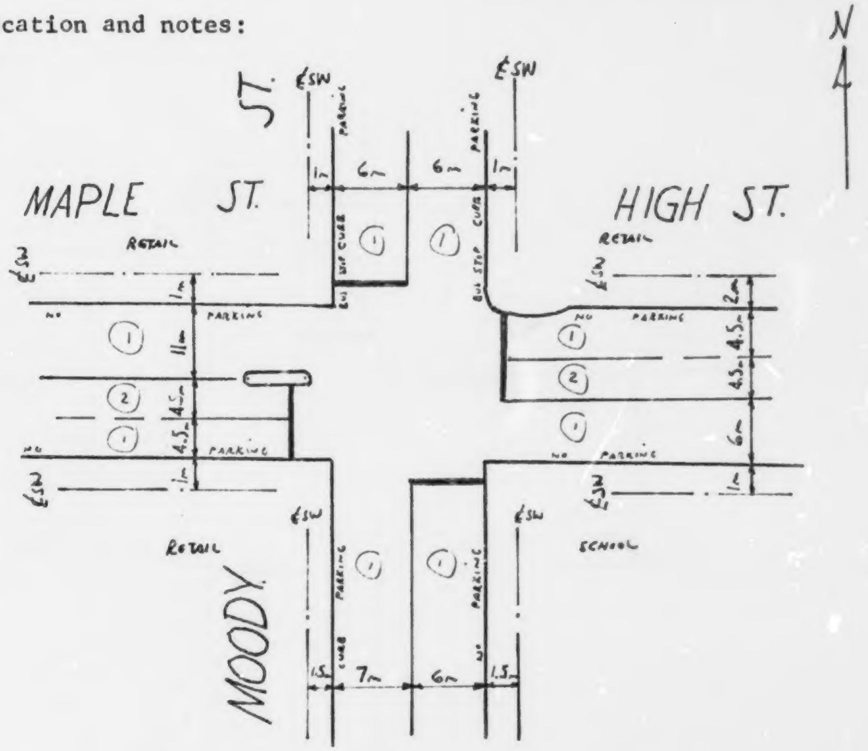
5) Police directs traffic during peak hours. Traffic signal off peak

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma. By: TPM

Location: Moody St. @ Maple & High Sts. Date: 26 Sep '75

Sketch of location and notes:



N
MAPLE ST.
HIGH ST.
MOODY ST.
℄SW
PARKING
NO PARKING
BUS STOP CURB
RETAIL
SCHOOL
1m
6m
7m
1.5m
2m
4.5m
11m
①
②

Notes:

1) Parking as shown
2) Receptors at ℄ sidewalk
3) Est. departure cruise speed is 20mph
4) Insignificant pedestrian interference during peak hours
5) Traffic signal controls

HOT SPOT VERIFICATION SUMMARY

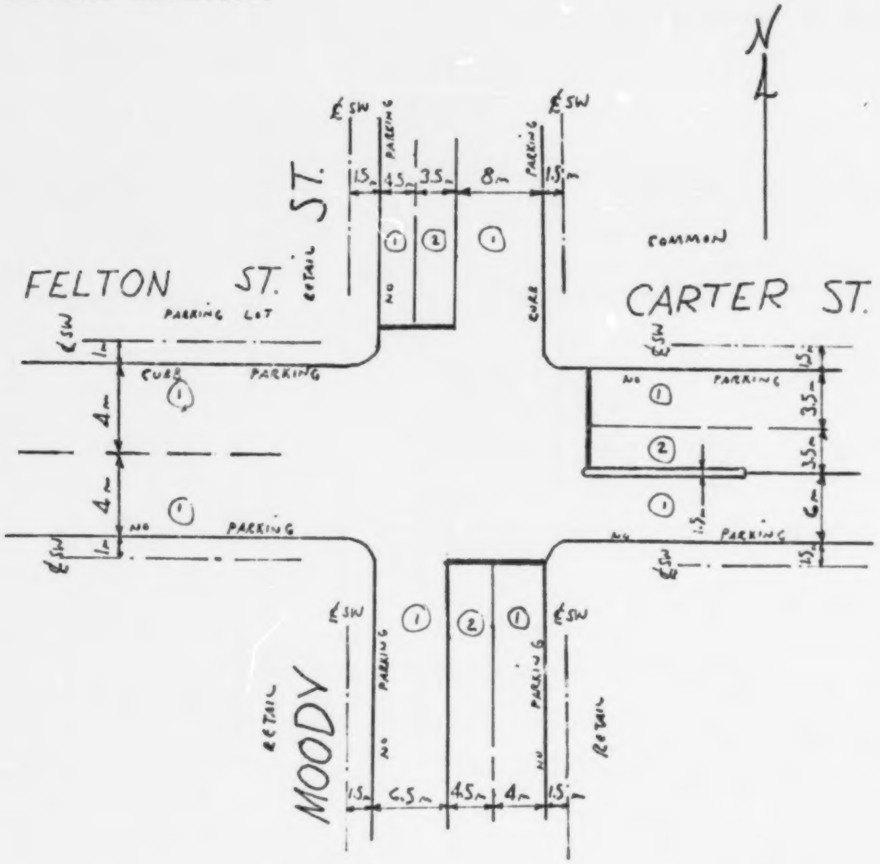
City/Town: Waltham, Ma.

By: TPM

Location: Moody St. @ Carter & Felton Sts.

Date: 26 Sep'75

Sketch of location and notes:


N
℄SW
PARKING
NO
1.5m
4.5m
3.5m
8m
ST.
FELTON ST.
RETAIL
PARKING LOT
CURB
COMMON
CARTER ST.
4m
6m
MOODY
6.5m
①
②

NOTES:

1) PARKING AS SHOWN

2) RECEPTORS AT ℄ SIDEWALK

3) No PEDESTRIAN INTERFERENCE

4) EST. DEPARTURE CRUISE SPEED is 20mph

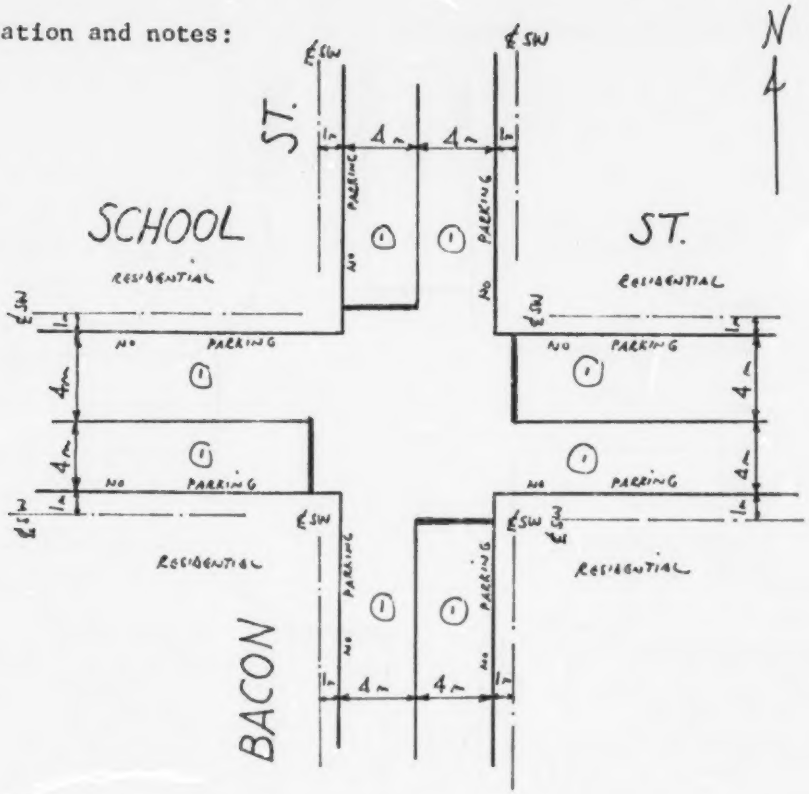
5) TRAFFIC SIGNAL CONTROLS

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma. By: TPM

Location: Bacon St. @ School St. Date: 26 Sep '75

Sketch of location and notes:


N
SCHOOL ST.
BACON ST.
℄SW
1m
4m
NO PARKING
PARKING
RESIDENTIAL
①

Notes:

1) Parking as shown

2) Receptors at ℄ sidewalk

3) No pedestrian interference

4) Assume departure cruise speed is 30 mph

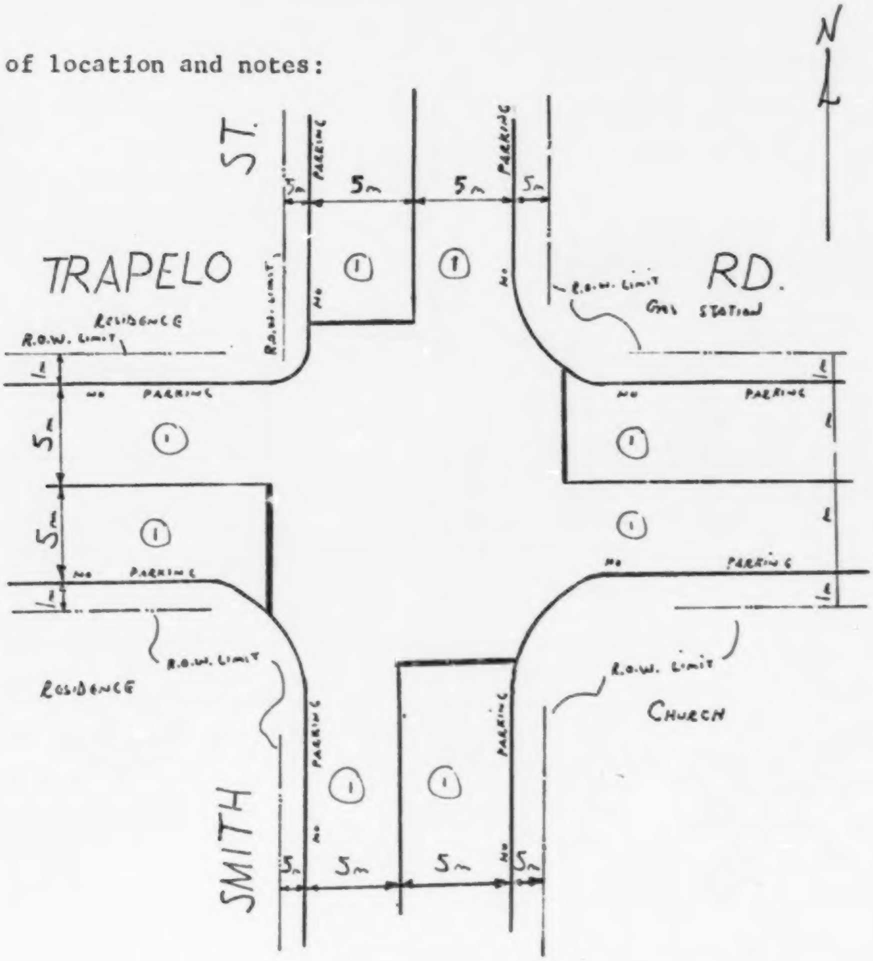
5) Traffic signal controls

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma. By: TPM

Location: Trapelo Rd. @ Smith St. Date: 26 Sep '75

Sketch of location and notes:


N
TRAPELO
RD.
SMITH
ST.
PARKING
NO PARKING
5m
1m
①
R.O.W. LIMIT
RESIDENCE
GAS STATION
CHURCH

Notes:

1) Parking as shown

2) Receptors at R.O.W. limit

3) Est. departure cruise speed is 30 mph

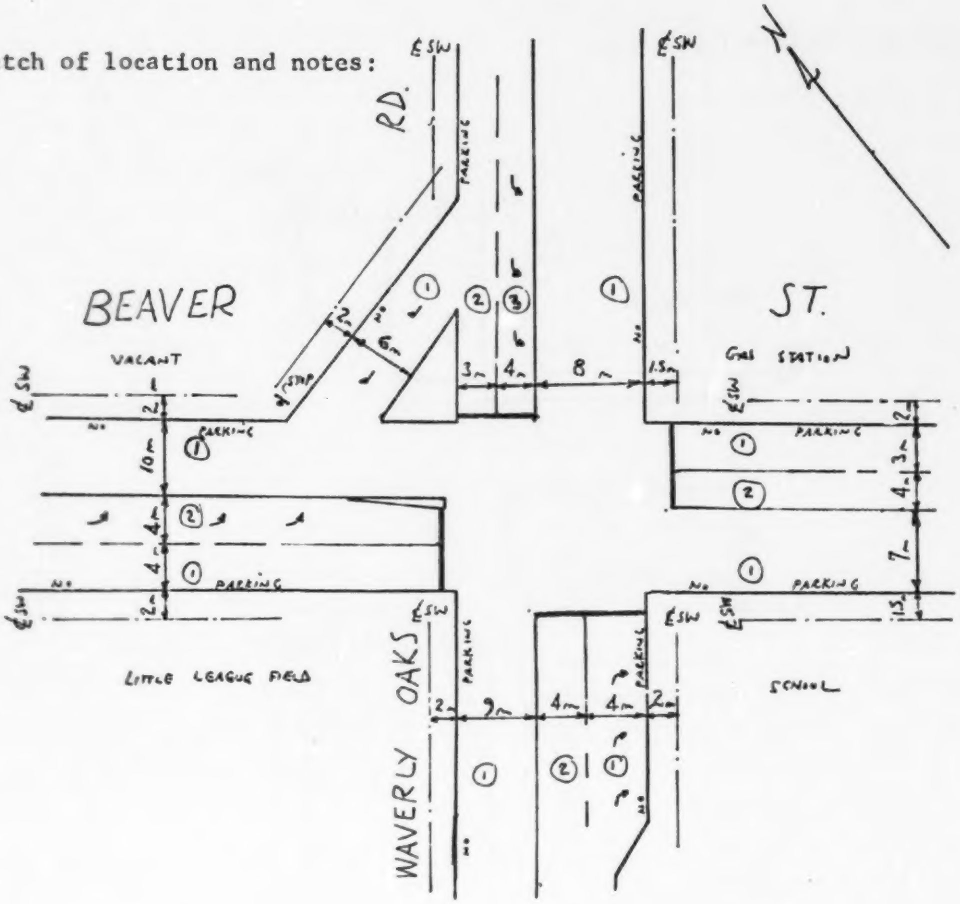
4) Traffic signal control

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma. By: TPM

Location: Waverly Oaks Road @ Beaver St. Date: 26 Sep 75

Sketch of location and notes:



N
BEAVER
ST.
RD.
WAVERLY OAKS
℄SW
PARKING
NO PARKING
VACANT
GAS STATION
LITTLE LEAGUE FIELD
SCHOOL
STOP
①
②
③
2m
6m
3m
4m
8m
1.5m
10m
7m
9m

Notes:

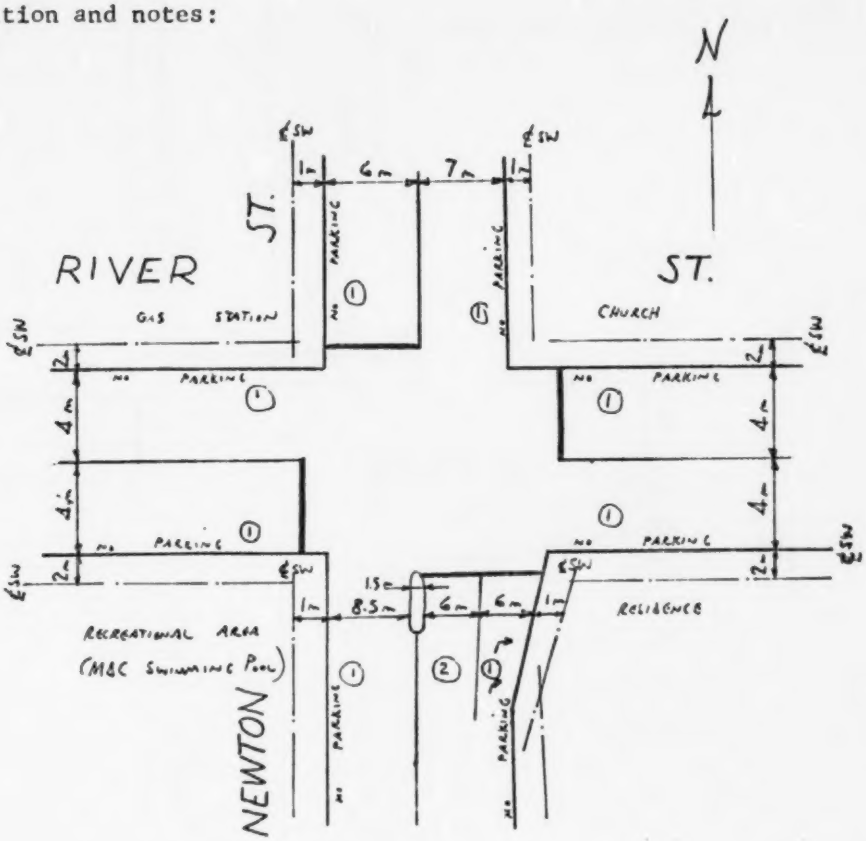
1) Parking as shown
2) Receptors at ℄ sidewalk
3) No pedestrian interference during peak hours
4) Est. departure cruise speed is 30 mph
5) Traffic signal controls all except right turn from Waverly Oaks Rd. S/B

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma. By: TPM

Location: Newton St. @ River St. Date: 26 Sep '75

Sketch of location and notes:


N
℄ SW
1m
6m
7m
1m
℄ SW
ST.
RIVER
ST.
No Parking
①
No Parking
①
Gas Station
Church
℄ SW
2m
No Parking
①
4m
4m
No Parking
①
2m
℄ SW
℄ SW
2m
No Parking
①
4m
4m
No Parking
①
℄ SW
2m
℄ SW
℄ SW
1.5m
1m
8.5m
6m
6m
1m
Residence
Recreational Area
(MDC Swimming Pool)
①
②
①
No Parking
No Parking
NEWTON

Notes:

1) Parking as shown

2) Receptors at ℄ sidewalk

3) No pedestrian interference

4) Est. departure cruise speeds : 30 mph

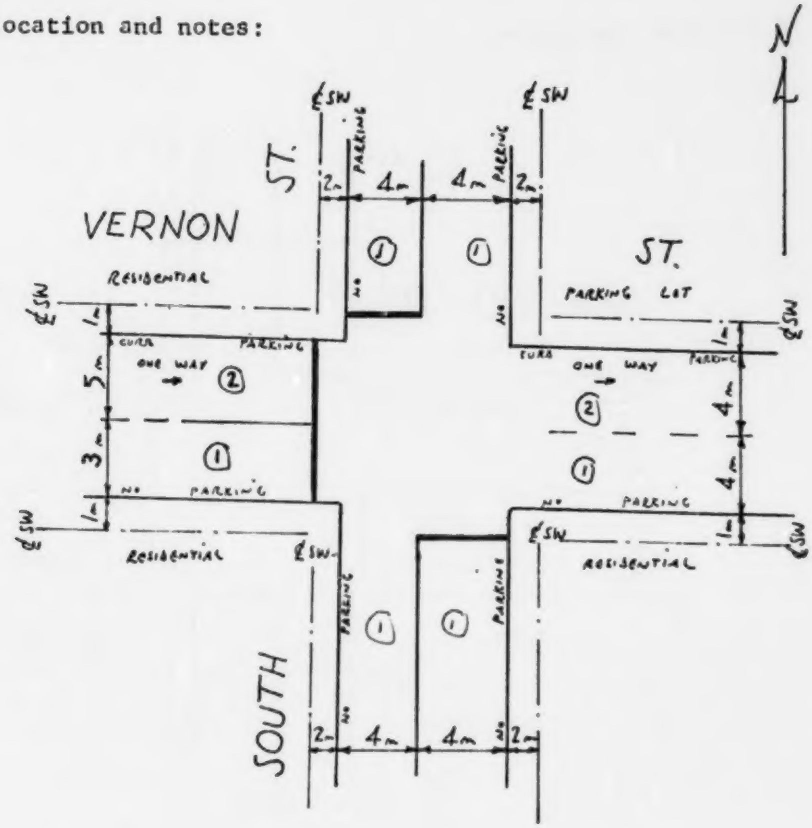
5) Traffic signal control

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma By: TPM

Location: South St. @ Vernon St. Date: 26 Sep '75

Sketch of location and notes:


N
℄SW
℄SW
ST.
PARKING
PARKING
2m
4m
4m
2m
VERNON
①
①
ST.
RESIDENTIAL
PARKING LOT
NO
NO
℄SW
℄SW
1m
1m
CURB PARKING
CURB PARKING
ONE WAY
ONE WAY
②
②
5m
4m
3m
4m
①
①
NO PARKING
NO PARKING
1m
1m
℄SW
℄SW
RESIDENTIAL
RESIDENTIAL
℄SW
℄SW
PARKING
PARKING
①
①
SOUTH
NO
NO
2m
4m
4m
2m

Notes:

1) Parking as shown

2) Receptors at ℄ sidewalk

3) No pedestrian interference during peak hours

4) Est departure cruise speed is 30mph

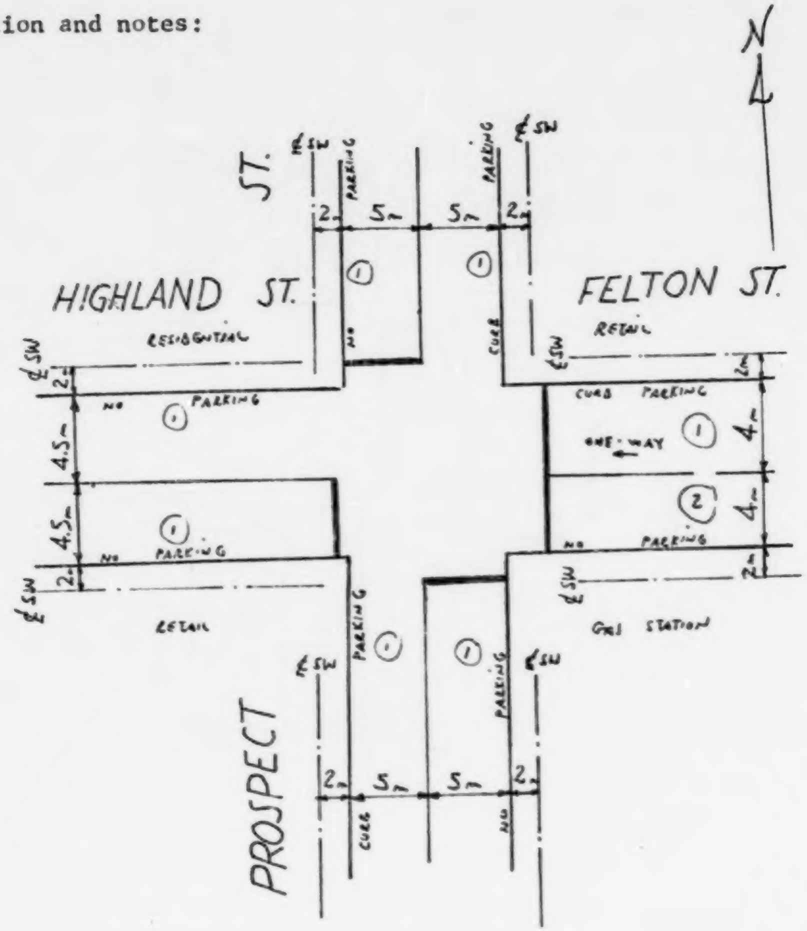
5) Traffic signal controls

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma. By: TPM

Location: Prospect St. @ Highland and Felton Sts. Date: 26 Sep '75

Sketch of location and notes:



N
HIGHLAND ST.
FELTON ST.
PROSPECT ST.
℄ SW
PARKING
NO PARKING
CURB
CURB PARKING
NO PARKING
RESIDENTIAL
RETAIL
RETAIL
GAS STATION
ONE-WAY
2m
5m
4.5m
4m
①
②

Notes:

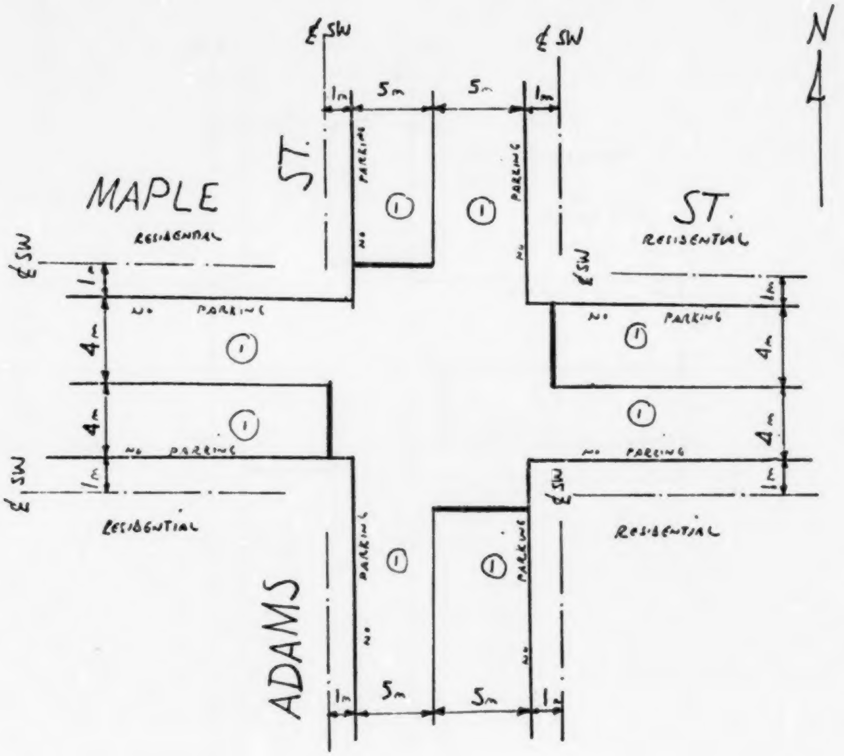
1) Parking as shown
2) Receptors at ℄ sidewalk
3) No pedestrian interference during peak hours
4) Est. cruise speed is 20 mph
5) Traffic signal controls

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma. By: TPM

Location: Adams St. @ Maple St. Date: 26 Sep '75

Sketch of location and notes:



℄ SW
℄ SW
N
1m
5m
5m
1m
ST.
MAPLE
ST.
RESIDENTIAL
RESIDENTIAL
NO PARKING
NO PARKING
①
1m
4m
4m
1m
℄ SW
℄ SW
NO PARKING
NO PARKING
RESIDENTIAL
RESIDENTIAL
ADAMS
1m
5m
5m
1m

NOTES:

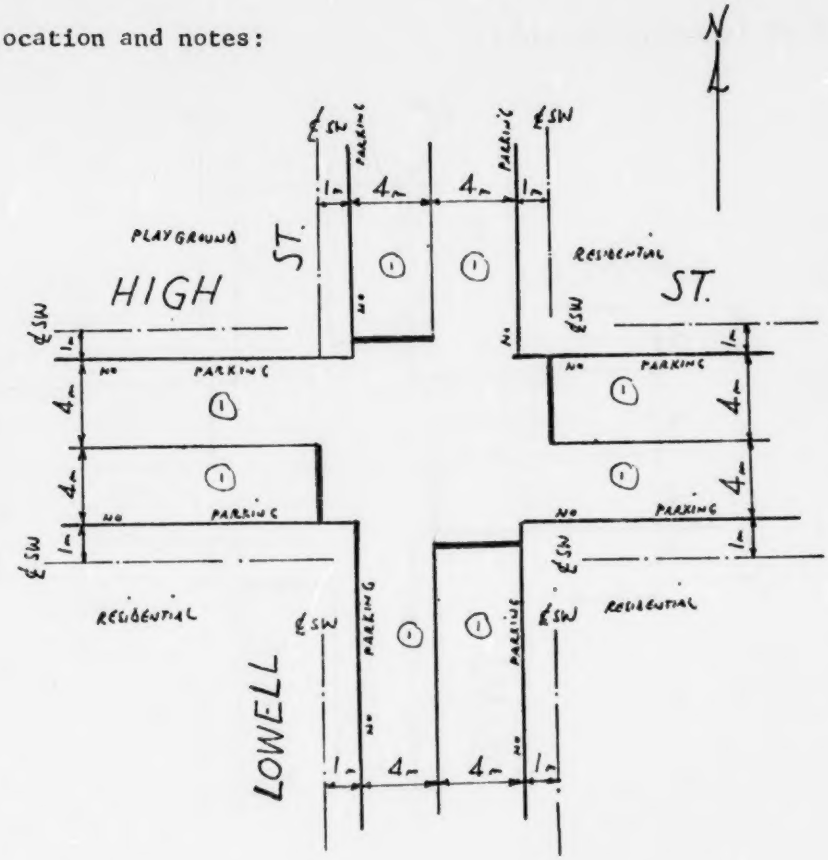
1) Parking as shown
2) Receptors at ℄ sidewalk
3) No pedestrian interference during peak hours
4) Est. departure cruise speed is 30mph
5) Traffic signal controls

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma. By: TPM

Location: Lowell St. @ High St. Date: 26 Sep '75

Sketch of location and notes:


N
℄SW
PARKING
1m
4m
4m
1m
PLAYGROUND
HIGH
ST.
ST.
RESIDENTIAL
NO PARKING
NO PARKING
①
RESIDENTIAL
RESIDENTIAL
LOWELL

Notes:

1) Parking as shown

2) Receptors at ℄ sidewalk

3) No pedestrian interference

4) Est. departure cruise speed is 30mph

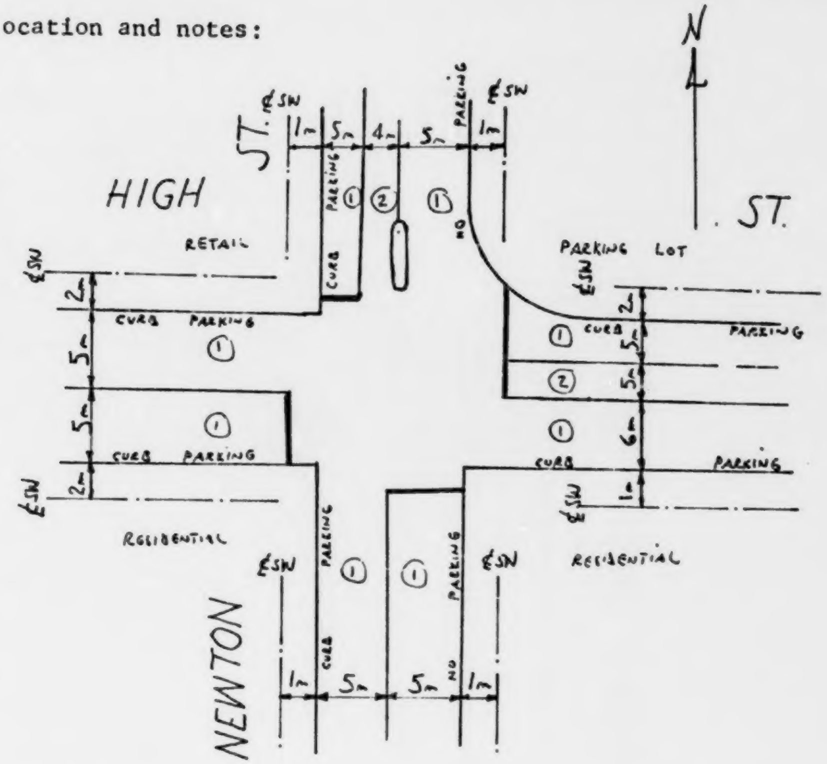
5) Traffic signal controls

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma. By: TPM

Location: Newton St. @ High St. Date: 26 Sep '75

Sketch of location and notes:



N
HIGH ST.
NEWTON ST.
℄SW
1m
5m
4m
2m
6m
PARKING
NO PARKING
CURB
CURB PARKING
RETAIL
PARKING LOT
RESIDENTIAL
①
②

Notes:

1) Parking as shown

2) Receptors at ℄ sidewalk

3) Insignificant pedestrian interference

4) Est. departure cruise speed is 25mph

5) Free right turn from High St. w/b, no interference

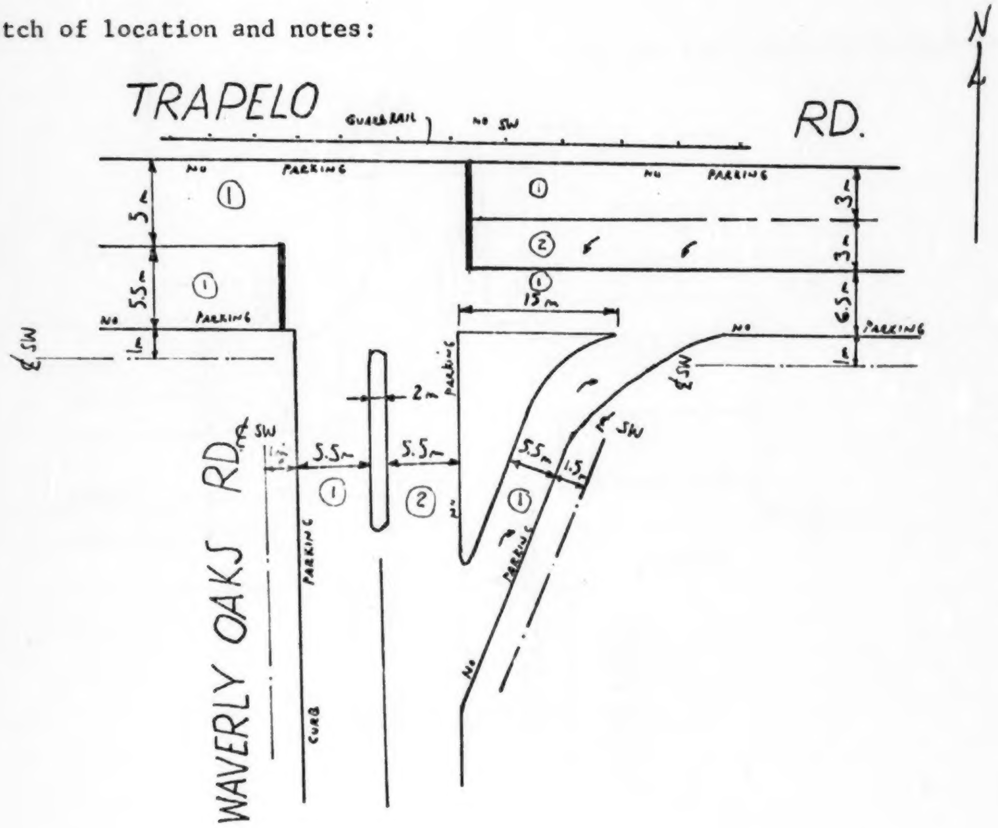
6) Traffic signal controls

HOT SPOT VERIFICATION SUMMARY

City/Town: WALTHAM, MA. By: TPM

Location: TRAPELO ROAD @ WAVERLY OAKS ROAD Date: 26 SEP '75

Sketch of location and notes:


N
TRAPELO
RD.
GUARDRAIL
NO SW
NO PARKING
NO PARKING
①
②
3m
3m
5m
5.5m
1m
1m
6.5m
NO PARKING
NO PARKING
℄ SW
℄ SW
℄ SW
13m
2m
1.5m
5.5m
5.5m
5.5m
1.5m
WAVERLY OAKS RD.
PARKING
PARKING
CURB
NO PARKING

NOTES:

1) PARKING AS SHOWN

2) RECEPTORS AT ℄ SIDEWALK; NO REASONABLE RESEPTOR ON NORTH SIDE OF TRAPELO ROAD

3) FREE-RIGHT TURN FROM WAVERLY OAKS ROAD; VIRTUALLY UNINTERRUPTED

4) TRAFFIC SIGNAL CONTROLS

5) EST. DEPARTURE CRUISE SPEED IS 30 mph

HOT SPOT VERIFICATION SUMMARY

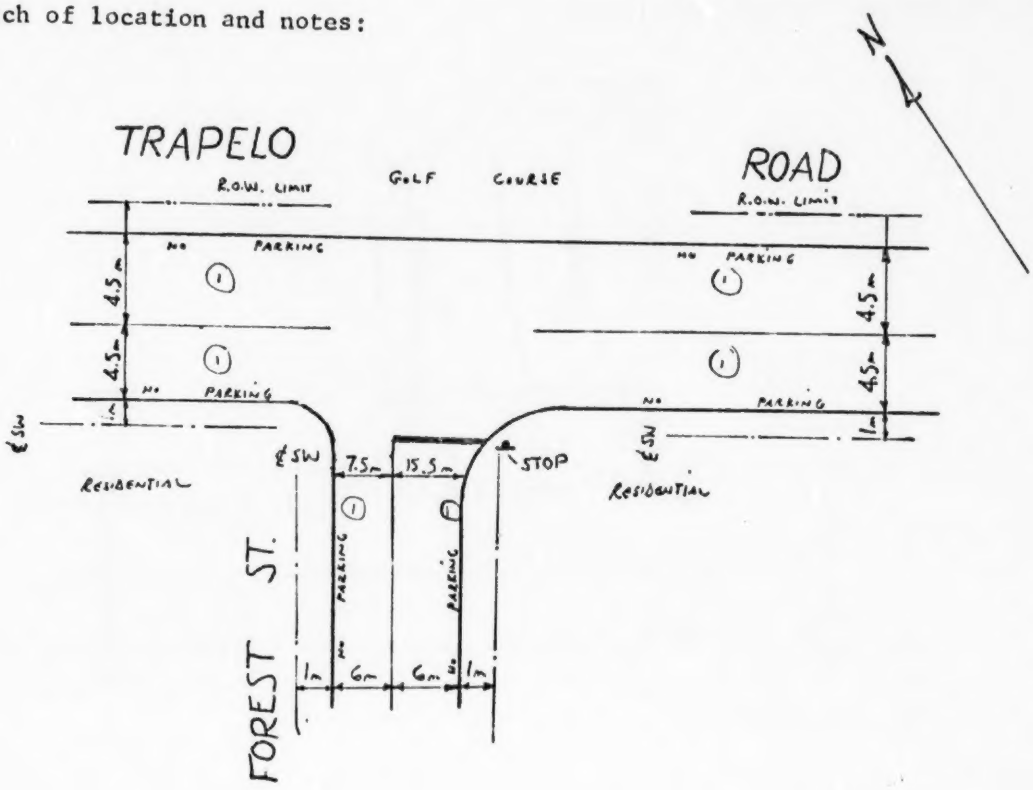
City/Town: Waltham, Ma

By: TPM

Location: Trapelo Rd @ Forest St.

Date: 26 Sep '75

Sketch of location and notes:


N
TRAPELO
ROAD
R.O.W. LIMIT
GOLF COURSE
R.O.W. LIMIT
NO PARKING
NO PARKING
①
①
4.5m
4.5m
①
①
4.5m
4.5m
NO PARKING
NO PARKING
1m
1m
℄SW
℄SW
℄SW
7.5m
15.5m
STOP
RESIDENTIAL
RESIDENTIAL
①
①
FOREST ST.
NO PARKING
PARKING
1m
6m
6m
1m

Notes:

1) Parking as shown

2) Receptors at ℄ sidewalk; no reasonable receptor on north side of Trapelo Road

3) Est. departure speed is 30 mph

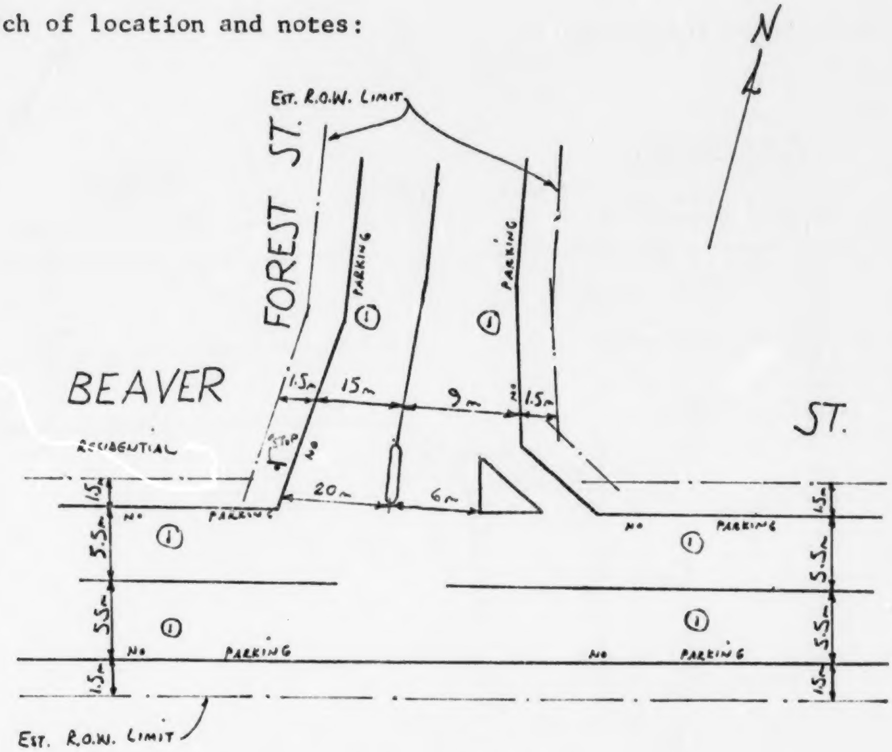
4) STOP sign control on Forest St.

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma. By: TPM

Location: Beaver St. @ Forest St. Date: 26 Sep '75

Sketch of location and notes:



N
Est. R.O.W. Limit
FOREST ST.
Parking
Parking
①
①
BEAVER
ST.
1.5m
15m
9m
1.5m
Residential
STOP
20m
6m
No Parking
No Parking
No Parking
No Parking
①
①
①
①
1.5m
5.5m
5.5m
1.5m
Est. R.O.W. Limit

Notes:

1) Parking as shown

2) Receptors are at R.O.W. lines; No apparent reasonable receptor on south side of Beaver St.

3) Est. departure cruise speed is 30 mph

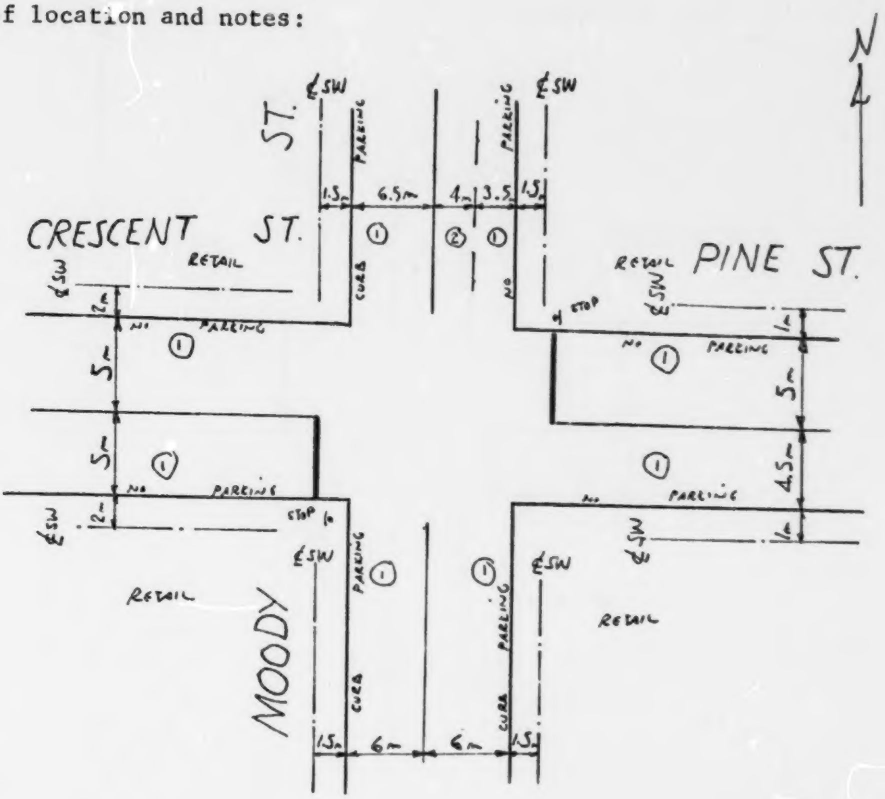
4) STOP-sign control on Forest St.

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma. By: TPM

Location: Moody St. @ Pine & Crescent Sts. Date: 26 Sep '75

Sketch of location and notes:


N
℄SW
ST.
PARKING
1.5m
6.5m
4m
3.5
1.5
CRESCENT ST.
RETAIL
①
②
①
PINE ST.
RETAIL
CURB
NO
STOP
℄SW
2m
NO PARKING
5m
①
1m
NO PARKING
5m
4.5m
①
①
2m
NO PARKING
STOP
℄SW
PARKING
①
①
℄SW
RETAIL
RETAIL
MOODY
CURB
PARKING
CURB
1.5m
6m
6m
1.5m

Notes:

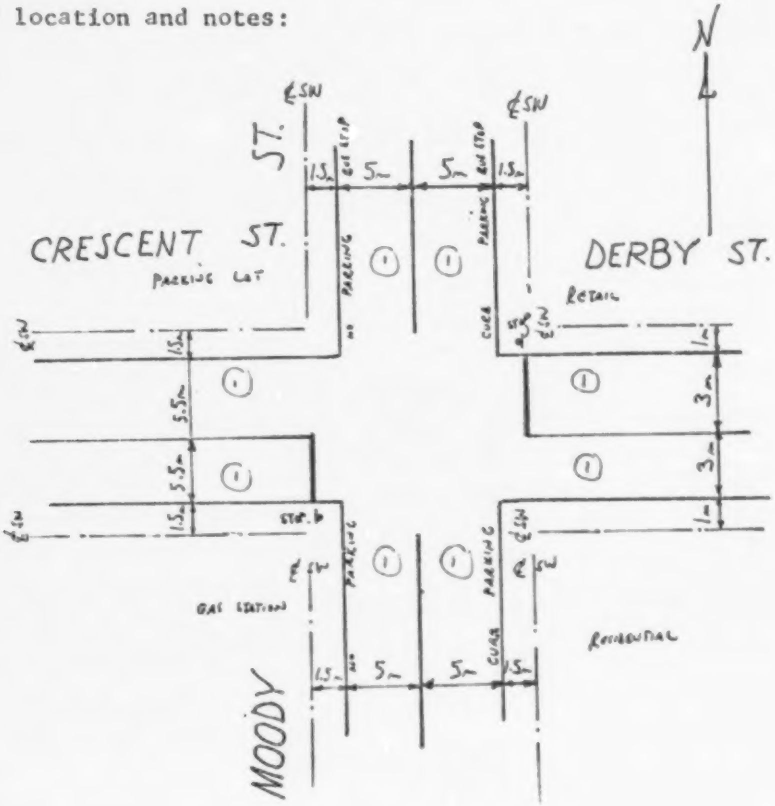
1) Parking as shown
2) Receptors at ℄ sidewalk
3) Insignificant pedestrian interference during peak hour!
4) Est. departure speed is 20 mph
5) STOP signs present on Crescent & Pine Sts., police used to direct traffic during the day (Analyze as though actuated signal control were present)

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma. By: TPM

Location: Moody St. @ Crescent & Derby Sts. Date: 26 Sep '75

Sketch of location and notes:


N
℄SW
℄SW
℄SW
℄SW
℄SW
℄SW
℄SW
℄SW
CRESCENT ST.
DERBY ST.
MOODY ST.
PARKING LOT
RETAIL
GAS STATION
RESIDENTIAL
BUS STOP
BUS STOP
PARKING
PARKING
PARKING
PARKING
NO
NO
CURB
CURB
STOP
STOP
1.5m
1.5m
1.5m
1.5m
1.5m
1.5m
5m
5m
5m
5m
5.5m
5.5m
3m
3m
1m
1m
①
①
①
①
①
①
①
①

Notes:

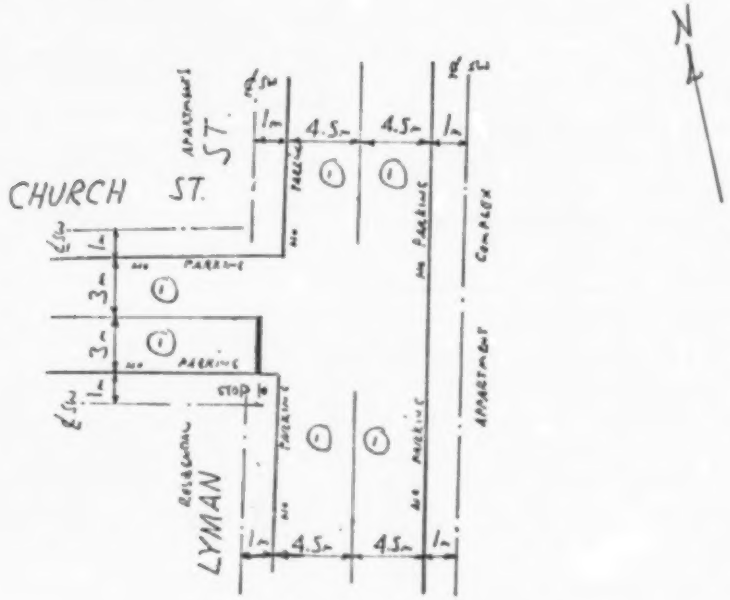
1) Parking as shown
2) Receptors at ℄ sidewalk
3) Est. departure cruise speed is 25 mph
4) Stop sign controls Crescent & Derby Sts.

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma. By: TPM

Location: Lyman St. @ Church St. Date: 26 Sep '75

Sketch of location and notes:



N
CHURCH ST.
LYMAN ST.
APARTMENTS
APARTMENT COMPLEX
RESIDENTIAL
℄ SW
℄ SW
℄ SW
℄ SW
1m
4.5m
4.5m
1m
1m
3m
3m
1m
1m
4.5m
4.5m
1m
①
NO PARKING
NO PARKING
NO PARKING
NO PARKING
NO PARKING
NO PARKING
STOP

Notes:

1) Parking as shown

2) Receptors at ℄ sidewalk

3) Est. departure speed is 25mph

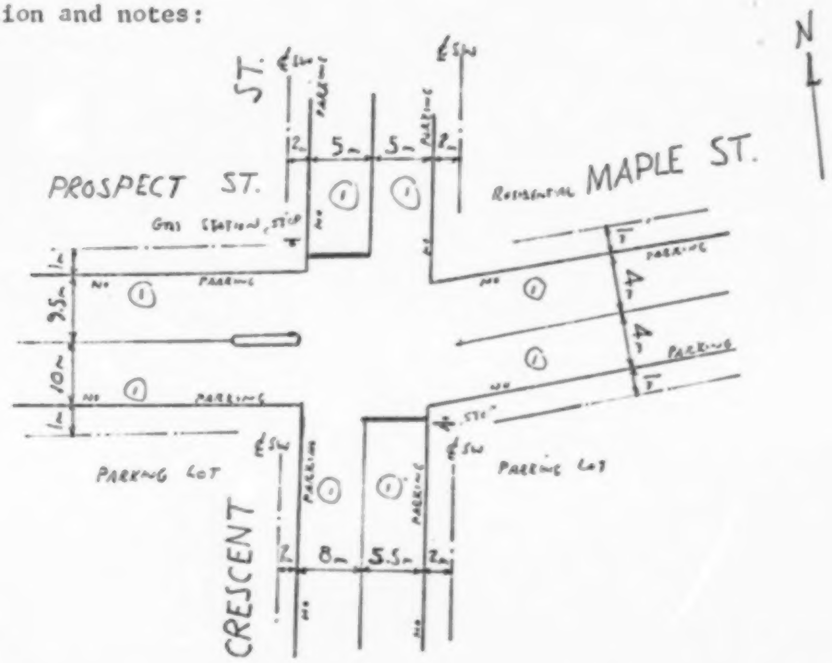
4) STOP sign controls Church St.

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma By: TPM

Location: Crescent St. @ Prospect & Maple Sts. Date: 26 Sep'75

Sketch of location and notes:


N
PROSPECT ST.
MAPLE ST.
CRESCENT ST.
℄ SW
℄ SW
℄ SW
℄ SW
PARKING
PARKING
PARKING
PARKING
PARKING
PARKING
NO PARKING
NO PARKING
NO
NO
2m
5m
5m
2m
1m
9.5m
10m
1m
4m
4m
8m
5.5m
2m
①
Gas Station, Stop
Residential
Parking Lot
Parking Lot
Stop

Notes:

1) Parking as shown

2) Receptors at ℄ sidewalk

3) Est. departure speed is 25mph

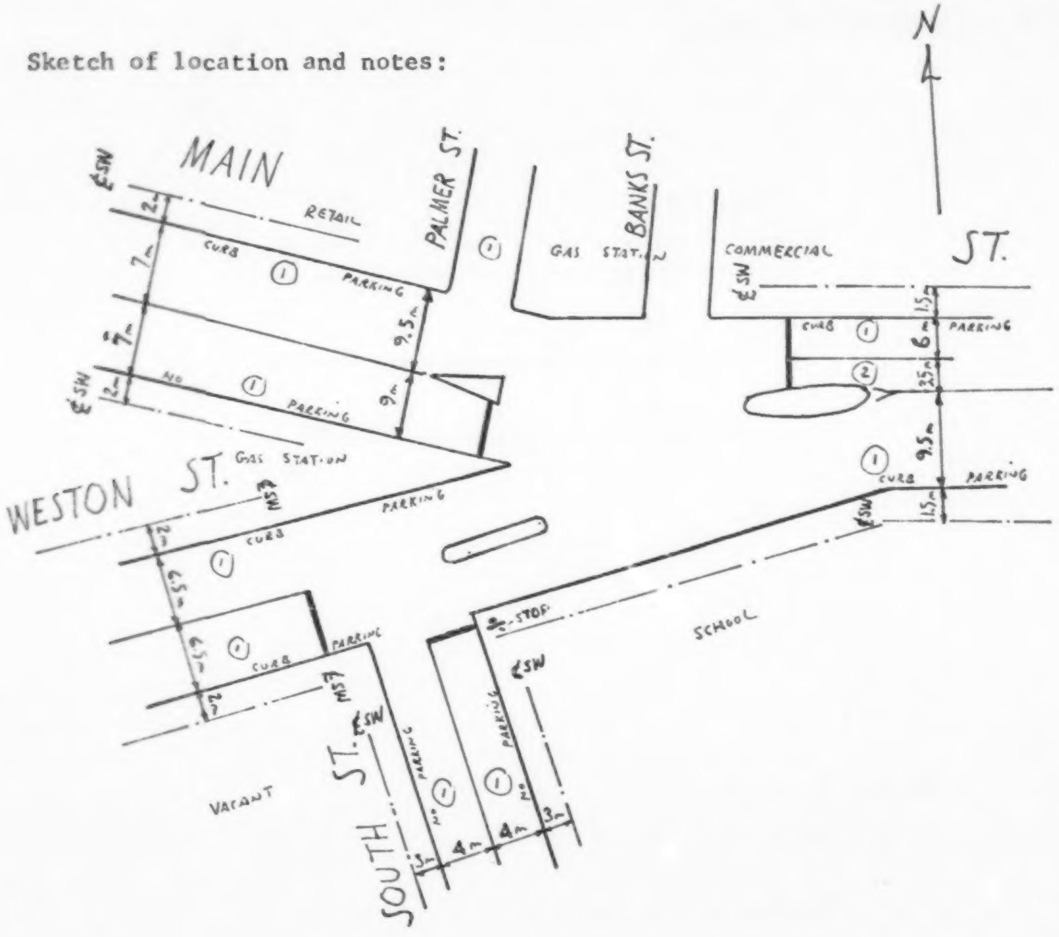
4) STOP sign controls Crescent St.

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma By: TPM

Location: Main St. @ Weston St. & South St. Date: 22 Sep '75

Sketch of location and notes:



N
MAIN
ST.
PALMER ST.
BANKS ST.
RETAIL
CURB
PARKING
NO PARKING
GAS STATION
COMMERCIAL
WESTON ST.
SOUTH ST.
SCHOOL
VACANT
STOP
℄SW
①
②
2m
7m
9.5m
9m
6.5m
1.5
6m
2.5m
3m
4m

Notes:

1) Parking as shown

2) Receptors at ℄ sidewalk

3) Insignificant pedestrian interference during peak hours

4) South Street controlled by flashing red

5) Mixed commercial/residential; Est. departure speeds - 25 mph on South St; 30 mph on Main and Weston Sts.

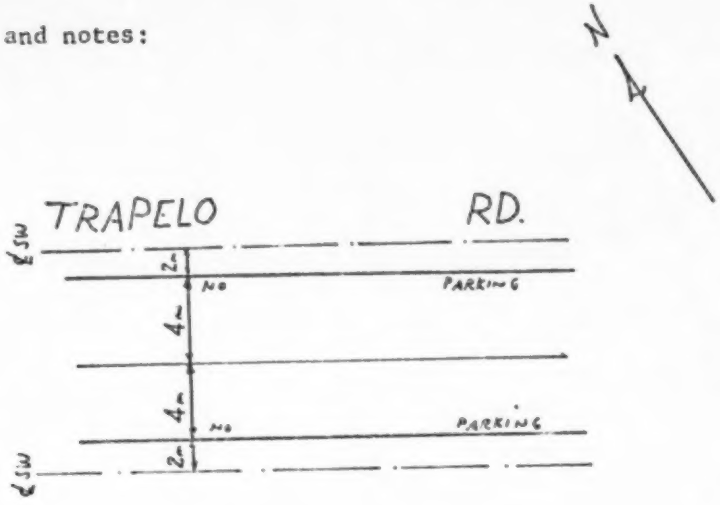
6) Traffic signals control all except South St.

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma. By: TPM

Location: Trapelo Rd. btwn Forest St. ; Waverly Oaks Rd. Date: 26 Sep '75

Sketch of location and notes:


N
TRAPELO RD.
℄ SW
2m
NO PARKING
4m
4m
NO PARKING
2m
℄ SW

Notes:

1) Parking as noted

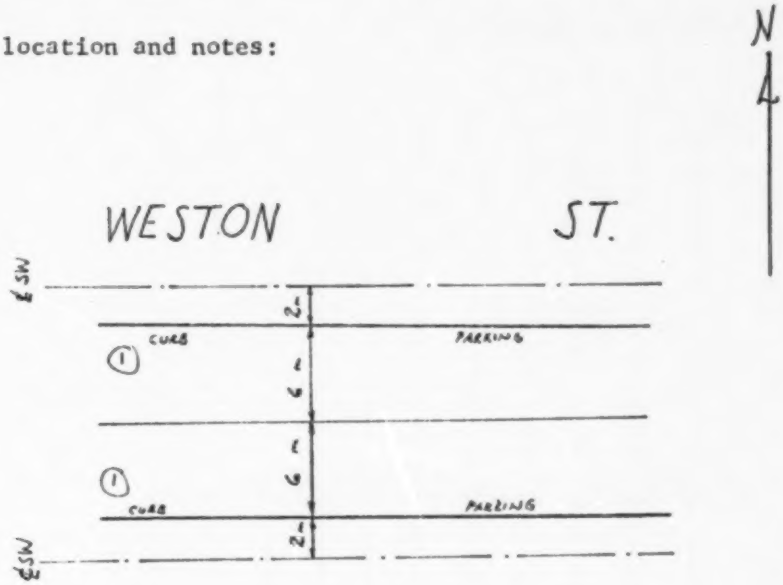
2) Receptor at ℄ sidewalk

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma. By: TPM

Location: Weston St. btwn Rt. 128 : Eddy St. Date: 26 Sep 75

Sketch of location and notes:


N
WESTON ST.
℄ SW
12'
CURB
①
PARKING
16'
16'
①
CURB
PARKING
12'
℄ SW

Notes:

1) Parking as shown

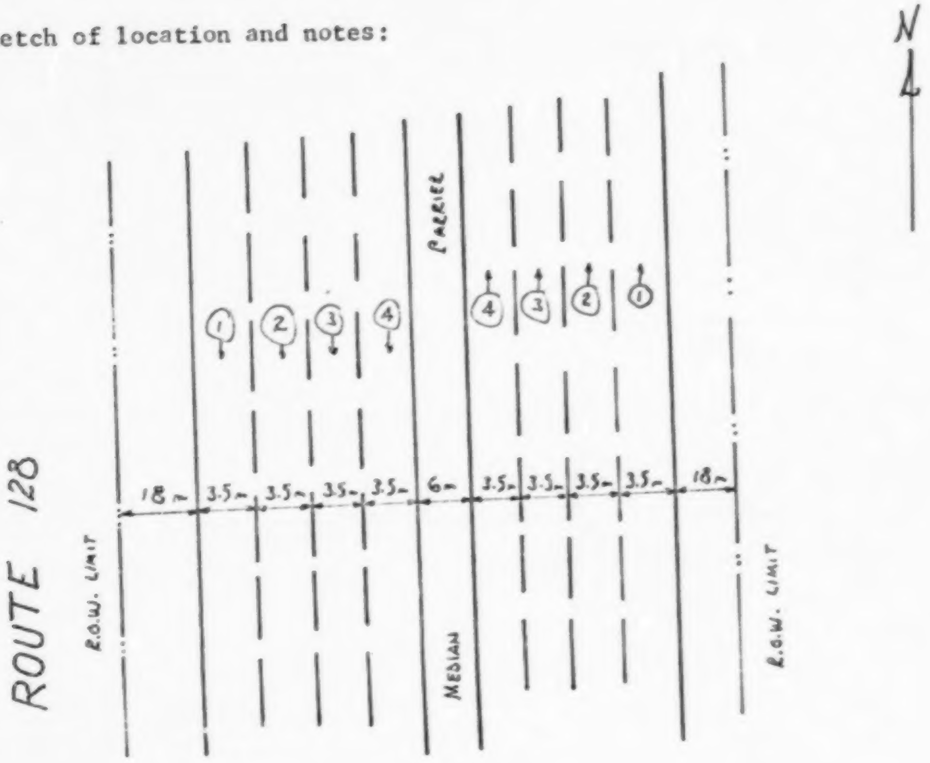
2) Receptor at ℄ sidewalk

HOT SPOT VERIFICATION SUMMARY

City/Town: Waltham, Ma. By: TPM

Location: Route 128 Between Main & Weston Sts. Date: 26 Sep '75

Sketch of location and notes:


N
ROUTE 128
R.O.W. LIMIT
BARRIER
MEDIAN
R.O.W. LIMIT
18m
3.5m
3.5m
3.5m
3.5m
6m
3.5m
3.5m
3.5m
3.5m
18m
①
②
③
④
④
③
②
①

Notes:

1) Level terrain

2) Receptor at R.O.W. limit